

LEAD TOXICITY

Environmental Alert

- Throughout the United States, children of all races and ethnic origins are at risk of lead toxicity
- In addition to renal disease, cardiovascular effects, and reproductive toxicity, lead may cause irreversible neurologic damage
- Blood lead levels once considered safe are now considered hazardous, with no known threshold
- Lead poisoning is a wholly preventable disease

This monograph is one in a series of self-instructional publications designed to increase the primary care provider's knowledge of hazardous substances in the environment and to aid in the evaluation of potentially exposed patients. This course is also available on the ATSDR Web site, www.atsdr.cdc.gov/HEC/CSEM/. See page 3 for more information about continuing medical education credits, continuing nursing education units, and continuing education units.



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Disclaimer

The state of knowledge regarding the treatment of patients potentially exposed to hazardous substances in the environment is constantly evolving and is often uncertain. In this monograph, ATSDR has made diligent effort to ensure the accuracy and currency of the information presented, but makes no claim that the document comprehensively addresses all possible situations related to this substance. This monograph is intended as an additional resource for physicians and other health professionals in assessing the condition and managing the treatment of patients potentially exposed to hazardous substances. It is not, however, a substitute for the professional judgment of a health care provider. The document must be interpreted in light of specific information regarding the patient and in conjunction with other sources of authority.

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Case Studies in Environmental Medicine (CSEM): Lead Toxicity

Goals and Objectives

The goal of the CSEM is to increase the primary care provider's knowledge of hazardous substances in the environment and to aid in the evaluation of potentially exposed patients.

After completion of this educational activity, the reader should be able to discuss the major exposure route for lead, describe two potential environmental and occupational sources of lead exposure, give two reasons lead is a health hazard, describe three factors contributing to lead toxicity, identify evaluation and treatment protocols for persons exposed to lead, and list two sources of information on lead.

Accreditation

Continuing Medical Education (CME)

The Centers for Disease Control and Prevention (CDC) is accredited by the Accreditation Council for Continuing Medical Education (ACCME) to provide continuing medical education for physicians. CDC designates this educational activity for a maximum of 2.0 hours in category 1 credit toward the American Medical Association (AMA) Physician's Recognition Award. Each physician should claim only those hours of credit that he/she actually spent in the educational activity.

Continuing Nursing Education (CNE)

This activity for 2.2 contact hours is provided by CDC, which is accredited as a provider of continuing education in nursing by the American Nurses Credentialing Center's Commission on Accreditation.

Continuing Education Units (CEU)

CDC has been approved as an Authorized Provider of continuing education and training programs by the International Association for Continuing Education and Training and awards 0.2 continuing education units (CEUs).

Instructions

See page 4

The questionnaire and posttest must be completed and returned electronically, by fax, or by mail for eligibility to receive continuing education credit.

Instructions for Completing CSEM Online

1. Read this CSEM, *Lead Toxicity*; all answers are in the text.
2. Link to the MMWR/ATSDR Continuing Education General Information page (www.cdc.gov/atsdr/index.html).
3. Once you access this page, select the Continuing Education Opportunities link.
4. Once you access the MMWR/ATSDR site online system, select the electronic file and/or register and test for a particular ATSDR course.
 - a. Under the heading “Register and Take Exam,” click on the test type desired.
 - b. If you have registered in this system before, please use the same login and password. This will ensure an accurate transcript.
 - c. If you have not previously registered in this system, please provide the registration information requested. This allows accurate tracking for credit purposes. Please review the CDC Privacy Notice (www.cdc.gov/privacy.htm).
 - d. Once you have logged in/registered, select the test and take the posttest.
5. Answer the questions presented. To receive continuing education credit, you must answer all of the questions. Some questions have more than one answer. Questions with more than one answer will instruct you to “indicate all that are true.”
6. Complete the course evaluation and posttest no later than **October 3, 2003**.
7. You will be able to immediately print your continuing education certificate from your personal transcript.

Instructions for Completing CSEM on Paper

1. Read this CSEM, *Lead Toxicity*; all answers are in the text.
2. Complete the evaluation questionnaire and posttest, including your name, mailing address, phone number, and e-mail address, if available.
3. Circle your answers to the questions. To receive your continuing education credit, you must answer all of the questions.
4. Sign and date the posttest.
5. Return the evaluation questionnaire and posttest, no later than **September 3, 2003**, to CDC by mail or fax:

Mail	or	Fax
Continuing Education Coordinator		404-498-0061
Division of Health Education and Promotion, ATSDR		ATTN: Continuing Education Coordinator
1600 Clifton Road, NE (MS E-33)		
Atlanta, GA 30333		
6. You will receive an award certificate within 90 days of submitting your credit forms. No fees are charged for participating in this continuing education activity.

Case Study

A father brings his 2-year-old boy into a pediatrician's office for a normal check-up on a Saturday in the late fall. The doctor examines the boy and proclaims him to be in fine physical health. The boy's growth and development indicators are standard for his age. From the father, the doctor learns that the boy's parents are divorced and that he generally lives with his mother and her parents. (The mother had to accompany her parents to her aunt's funeral this weekend and therefore could not make the appointment.) The doctor makes a note of this information.

Concerned that her child is hyperactive, the mother brings the same 5-year-old boy 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, and recommended evaluation by a physician as well as by the school psychologist. The mother states that he has always seemed restless and easily distracted, but that these first 6 months in kindergarten have been especially trying.

He has also complained recently of frequent intermittent abdominal pains and constipation. The mother has tried over-the-counter medicines as needed for this problem, and wonders if the change to attending kindergarten has a role in his increased complaints.

Family history reveals that the boy lives with his sister, mother, and maternal grandparents in an older suburb of your community. The child's monthly weekend visits to his father's house are working out fine. However, he seems to be fighting more with his sister, who has an attention-deficit disorder and is repeating first grade. Since the mother moved in with her parents after her divorce 4 years ago, she has worked with the grandfather in an automobile radiator repair shop, where her children often come to play after school. She was just laid off, however, and expressed worry about increasing financial dependence on her parents. 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. Her third child is due in 4 months.

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 previous pica behavior. Spun hematocrit was diminished at 30%. Peripheral blood smear showed hypochromia and microcytosis. There was no evidence of

An apparently normal 2-year-old becomes a hyperactive 5-year-old with disturbed hearing, hypochromic anemia, and abdominal pain

Three years later ...

Pretest

- (a) *Is there any information that the previous physician should have asked about or looked for (or did not note down) when the boy was brought in as a 2-year-old?*
- (b) *What should be included in this boy's problem list?*
- (c) *List several possible causes for the anemia.*
- (d) *What tests would you order to confirm or rule out your diagnosis?*

blood loss, and stool examination was negative for occult blood. The diagnosis was “mild iron deficiency anemia,” and iron therapy 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 receives no medications at this time and has no known allergies.

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

Who's at Risk

Today everyone is exposed to environmental lead. Exposure to lead and lead chemicals occurs from breathing air, drinking water, eating foods, and swallowing or touching dust or dirt that contains lead. With the phasing out of lead in gasoline (which began in the 1970s), lead in paints and in soils and dusts have become the principal sources of exposure in the United States. The government has made many efforts to reduce residential exposure to lead, including instituting a phaseout of lead in gasoline, setting a maximum allowable lead content in paint of 0.06% in 1977, and setting an action level for lead in public drinking water and in occupational settings.

Both children and adults are susceptible to health effects from lead exposure, although the typical exposure pathways and effects are somewhat different. Children who reside in pre-1978 housing facilities (and especially those in inner cities or those built before 1950) and adults who are occupationally exposed are at greatest risk. Although many body systems can be severely affected by high chronic and acute lead exposure, lead is dangerous in large part because moderate or low but chronic exposure can affect the developing nervous system of young children in more subtle but damaging ways.

Lead exposure is an international issue. Lead mining, lead smelting, and use of leaded gasoline are common in many developing countries, where children and adults could receive substantial lead exposure (Kaul et al. 1999; Rothenberg et al. 1994; Factor-Litvak et al. 1999; López-Carrillo et al. 1996; Wasserman et al. 1997). When appropriate, a medical history should include questions about living conditions in previous and current residences.

Children

The good news is that children's exposure to lead, as indicated by their blood lead levels (BLLs), has declined significantly since the 1970s. Average BLLs for children have dropped more than 80% over this time period (Centers for Disease Control and Prevention [CDC] 1997a). In 1984, 17% of children in the United States were estimated to be at risk of lead poisoning, whereas a 1991–1994 study showed that only 4.4% of children ages 1–5 had BLLs ≥ 10 micrograms per deciliter ($\mu\text{g}/\text{dL}$), which is the CDC's recommended action level for lead exposure in children (American Academy of Pediatrics [AAP] 1993; CDC 1997a).

On the other hand, some populations of children are still at significant risk of lead poisoning. In particular, children who live in older housing are more likely to have elevated BLLs than the population of U.S. children as a whole. These children are more likely to be poor and from racial/ethnic minority groups. To illustrate, the same 1991–1994 national survey of children ages 1–5 that found that 4.4% of children nationwide had elevated BLLs ($\geq 10 \mu\text{g}/\text{dL}$) also found that (CDC 1997a, 1997b):

- 21.9% of black children living in older housing had elevated BLLs, and 11.2% of all black, non-Hispanic children had elevated BLLs
- 16.4% of poor children living in older housing had elevated BLLs
- 11.5% of children living in older housing in large urban areas (population of 1,000,000 or greater) had elevated BLLs.

For some local populations, the percentage of children with elevated BLLs may be even higher. In one study of 817 children ages 10 months through 6 years in an inner-city Philadelphia outpatient population, 68% had BLLs $\geq 10 \mu\text{g}/\text{dL}$ (Melman et al. 1998).

It is important to note, however, that no economic or racial/ethnic subgroup of children is free from the risk of having BLLs high enough to cause adverse health effects. Sizable numbers of children from families with incomes well above the poverty line have been diagnosed with lead poisoning, especially those children who live in older and/or renovated homes.

Because of their behavior and physiology, children are more sensitive than adults to exposure to lead in a given environment. For example, children generally come into contact with and, because of mouthing and hand-to-mouth behaviors, ingest soil particles and house dust (possibly mixed with paint chips) at higher rates than adults. This is especially true for children who exhibit compulsive hand-to-mouth behaviors or pica (repeated eating of nonfood items). Children (infants and toddlers) are closer to and spend

- Young children (especially those living in old houses with lead-based paint) have a high potential for lead exposure and are especially susceptible to its toxic effects. Poor children and children from racial/ethnic minority backgrounds are more likely to have elevated blood lead levels, but children from wealthier backgrounds and white children can also be at risk if, for example, they live in homeowner-renovated housing.
- Because a child's chronic exposure to low lead levels can cause developmental and neurologic problems that may be extremely difficult to detect through physical examination, environmental evaluation and blood lead screening are often necessary to assess whether a child is at risk.

more time on the ground, where they may come into contact with lead-contaminated soil/dust on carpets and floors. They also take in more food and water per body weight. In addition, absorption of lead is estimated to be as much as five to ten times greater in infants and young children than in adults (Alexander et al. 1974; Chamberlain et al. 1978; James et al. 1985; Ziegler et al. 1978). Gastrointestinal absorption of lead in children is increased with dietary deficiency of iron, calcium, zinc, and ascorbate (Mahaffey et al. 1990).

Finally, children are more sensitive than adults to elevated BLLs, in large part because their brain and nervous system (and other organ systems) are still developing. In particular, the incomplete development of the blood-brain barrier in fetuses and in very young children (up to 36 months of age) increases the risk of lead's entry into the developing nervous system, which can result in prolonged or permanent neurobehavioral disorders. Childhood lead exposure has been correlated with higher absenteeism in high school, lower class rank, poorer vocabulary and grammatical reasoning scores, longer reaction times, and poorer hand-eye coordination (American Academy of Pediatrics 1993). Children's renal, endocrine, and hematic systems may also be adversely affected by lead exposure. As more sensitive studies and measures are developed, the threshold exposure levels (as indicated by BLLs) for many of these effects are being revised downward.

Pregnant Women and Their Developing Fetuses

- Lead poses a substantial threat to pregnant women and their developing fetuses because blood lead readily crosses the placenta.
- Workers in occupational settings with sources of lead exposure (e.g., plumbers, miners, mechanics, and lead smelter/refinery workers) experience increased risk. Workers may also bring lead dust home on skin and clothes and unknowingly expose family members. Renovation and removal of lead paint using unsafe methods can also result in lead exposure.

Blood lead readily crosses the placenta, putting the developing fetus at risk. This is especially important in the neurologic development of the fetus because there is no blood-brain barrier. The mother's blood lead level is an important indication of risk to the fetus. In addition, mothers who had previous elevated exposure to lead may store it in their bones, from which it could be released during times of calcium stress, such as pregnancy and lactation.

Adults

Although children are at greatest risk from lead exposure, adult exposures can also result in harmful health effects. Most adult exposures are occupational and occur in lead-related industries such as lead smelting, refining, and manufacturing industries. Workers may inhale lead dust and lead oxide fumes, as well as eat, drink, and smoke in or near contaminated areas, thereby increasing their probability of lead ingestion. Between 0.5 and 1.5 million workers are exposed to lead in the workplace (ATSDR 1999). If showers and changes of clothing are not provided, workers can bring lead dust home on their skin, shoes, and clothing, thus inadvertently

exposing family members. Adults can also be exposed during certain hobbies and activities where lead is used, during renovation or removal of lead paint, or from certain lead-containing cosmetics (non-Western) and home health remedies.

Other than the developmental effects unique to young children (such as developmental neurologic effects and possibly attention-deficit hyperactivity disorder [ADHD]), the health effects experienced from adult exposures are similar to those experienced by children, although the thresholds are generally higher. There have been reproductive effects associated with lead exposure, although some results are controversial, especially at lower levels of exposure. Pregnant women with elevated BLLs may have an increased chance of miscarriage, spontaneous abortion or stillbirth, and preterm labor, and newborns with low birth weight or neurologic problems.

Exposure Pathways

Lead is a naturally occurring element that people have used almost since the beginning of civilization. Human activities have spread lead widely throughout the environment—the air, water, soil, plants, animals, and man-made constructions. Because lead is spread so widely throughout the environment, it can now be found in everyone's bodies (Flegal and Smith 1992, 1995) within an order of magnitude of levels that have resulted in adverse health effects (Budd et al., 1998).

Most human exposure to lead occurs through ingestion or inhalation. Lead exposure in the general population (including children) occurs primarily through ingestion, although inhalation also contributes to lead body burden and may be the major contributor for workers in lead-related occupations. Almost all inhaled lead is absorbed into the body, whereas from 20% to 70% of ingested lead is absorbed (with children generally absorbing a higher percentage than adults—see *Biologic Fate*; ATSDR 1999). The U.S. general public is not likely to encounter lead that readily enters the human body through the skin (dermal exposure) because leaded gasoline additives are no longer used. Note also that lead, once absorbed into the body, may be stored for long periods in mineralizing tissue (i.e., teeth and bones) and then released again into the bloodstream, especially in times of calcium stress (e.g., pregnancy, lactation, osteoporosis), or calcium deficiency. This is endogenous exposure (see *Biologic Fate*). The major exogenous sources and associated pathways of lead exposure are discussed below.

Lead paint is the major source of lead exposure for children (American Academy of Pediatrics 1993; ATSDR 1999). Between 83% and 86% of all homes built before 1978 in the United States have lead-based paint in them (CDC 1997a). The older the house, the more likely it is to contain

- People who grew up or lived in developing countries may have been exposed to substantial amounts of lead.

Challenge

- (1) *Who else in the family or community discussed in the case study is in need of an environmental and/or BLL evaluation to determine his or her risk for lead exposure?*
- (2) *Evaluate the exposure potential and risk to the fetus mentioned in the case study.*

- Lead paint is a primary source of environmental exposure to lead.

lead-based paint and to have a higher concentration of lead in the paint. Before 1955, much white house paint contained up to 50% lead. 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). The amount of lead allowable in paint was lowered by federal law to 1% in 1971 and then to 0.06% in 1977.

As lead paint deteriorates, peels, chips, is removed (e.g., by renovation), or pulverizes because of friction (e.g., in window sills), house dust and surrounding soil may become contaminated. Lead then enters the body through normal hand-to-mouth activity and inhalation (Sayre et al. 1974). Children are also at increased risk from the ingestion of paint chips, and children with pica behavior are at even greater risk.

- Automobile emissions were a major source of exposure to lead before lead was phased out and then banned as a gasoline additive; much of the lead released to the air (in the past) and presently from industrial discharges is deposited onto the land or surface water.

The combustion of leaded gasoline generated approximately 90% of all anthropogenic lead emissions in 1984, and inhalation of these emissions was a significant exposure pathway (ATSDR 1999). Leaded gasoline additives were phased out beginning in the 1970s and were completely banned by the U.S. Environmental Protection Agency (EPA) as of February 1996. Although some industries still discharge lead to the air, inhalation is no longer the major exposure pathway for the U.S. public. In some other countries, however, leaded gasoline is still used, and the resulting emissions pose a major public health threat.

Much of the lead discharged to the air is ultimately brought back to the ground or surface water through wet or dry deposition. Past and present atmospheric emissions therefore contribute to the amount of lead in soils; areas of high traffic flow or near industrial sources are likely to have a greater concentration of lead in soils and dust than more remote areas (ATSDR 1999).

- Workers in up to 100 types of industries (and indirectly, their families) may have occupational exposure to lead.

Workers in the lead smelting, refining, and manufacturing industries experience the highest and most prolonged occupational exposures to lead (ATSDR 1999). Others at increased risk for lead exposure include workers in brass/bronze foundries, rubber products and plastics industries, soldering, steel welding/cutting operations, battery manufacturing plants, and other manufacturing industries (ATSDR 1999). Increased risk for occupational lead exposure also occurs among construction workers, bridge maintenance and repair workers, municipal waste incinerator workers, pottery/ceramics industry employees, radiator repair mechanics, and people who work with lead solder.

The major exposure pathways for workers are inhalation and ingestion of lead-bearing dust and fumes. It is important to note that occupational exposures can also result in secondary exposure for workers' families if

workers bring home lead-contaminated dust on their skin, clothes, or shoes. Workers can prevent secondary exposures by showering and/or changing clothing before returning home. Children may also be exposed to occupational lead sources if their parents work in these industries and allow their children to visit them at work. Many “cottage industries” are actually located in the home.

Lead may contaminate water, food, and alcohol, but the contaminant cannot be seen, tasted, or smelled (ATSDR 1999). Lead occurs in drinking water through leaching from lead-containing pipes, faucets, and solder, which can be found in plumbing of older buildings. Leaching rates accelerate when water is acidic or hot or when it has been standing in the pipes for extended periods (e.g., overnight). EPA disclosed that for calendar year 1996, 6 million people in the United States were served by public water systems reporting violations of the Lead and Copper Rule (EPA’s maximum level for lead in public drinking water systems is 15 µg/L; EPA 1996). Other potential sources of lead contamination include brass fixtures, older drinking-water coolers, and older coffee urns (Mushak et al. 1989). Boiling of water will not get rid of lead, but flushing standing water from the lines and faucet for a few minutes before use and using cold water for drinking will minimize exposure.

Lead may contaminate food during production, processing, and packaging. Production sources may include root vegetables’ uptake from soil lead or atmospheric lead deposition into leafy vegetables (Mushak et al. 1989). Until the U.S. phaseout of lead-soldered food cans during the 1980s, canned food was a major source of lead in the diets of Americans. Although some plastic food wrappers may be printed with lead-containing pigments, and although some food cans produced and sold in foreign countries may be lead soldered, the amount of lead in Americans’ diets has declined substantially. In the early 1980s, adults ingested approximately 56 µg/day of lead in food; estimates from the early 1990s ranged from 1.8 to 4.2 µg/day (ATSDR 1999).

Other sources of food contamination include some ceramic tableware (especially imported), lead-glazed pottery, leaded-crystal glassware, certain “natural” calcium supplements, and bright red and yellow paints on bread bags (ATSDR 1999; Mushak et al. 1989). Lead-glazed pottery, particularly if it is imported, is a potential source of exposure that is often overlooked. Even “safe” pottery and ceramic ware can become harmful to human health. For example, dishwashing may chip or wear off the protective glaze and expose people to lead-containing pigments. Other sources of lead exposure include wine and homemade alcohol (e.g., moonshine) that is distilled and/or stored in leaded containers.

- Drinking water, food, and alcohol are sources of environmental exposure to lead.

- Certain hobbies and activities may lead to lead exposure.

Certain hobbies, home activities, and car repairs (e.g., radiator repair) can contribute to lead exposure. Some of the more common hobbies include glazed-pottery making; artistic painting; stained-glass making; glass or metal soldering; target shooting; electronics soldering; and construction of bullets, slugs, or fishing sinkers. One frequently overlooked source of lead exposure is house renovation involving scraping, remodeling, or otherwise disturbing lead-based paint. (Renovation involving lead-based paint should only be undertaken after proper training, or by certified personnel.) People using paints, pigments, facial cosmetics, or hair coloring with lead or lead acetate also increase their lead exposure risk. Cosmetics containing lead include surma and kohl, which are popular in some Asian countries. Lastly, smoking cigarettes or breathing second-hand smoke increases exposure because tobacco smoke contains small amounts of lead.
- People living near hazardous waste sites, lead smelters/refineries, battery recycling/crushing centers or other industrial lead sources may be exposed to lead and chemicals that contain lead.

Industrial and mining activities may release lead and lead compounds into the air and soil. Such sources range in size from large mines and hazardous waste sites (e.g., Superfund sites) to small garages working with old car batteries. Local community members may be exposed to emissions from these sources through ingestion (or inhalation) of lead-contaminated dust or soils. Even abandoned industrial lead sites, such as old mines or lead smelters, may continue to pose a potential public health hazard.
- Certain folk remedies may also cause lead exposure.

Ingesting certain home remedy medicines may expose people to lead or lead compounds. Examples include *azarcon* and *greta*, Mexican folk remedies used to treat the coliclike illness *empacho*. *Azarcon* and *greta* are also known as *liga*, *Maria Luisa*, *alarcon*, *coral*, and *rueda*. Lead-containing remedies used by some Asian communities are *chuihong tokuwan*, *ghasard*, *bali goli*, and *kandu*. Middle Eastern remedies and cosmetics include *alkohl*, *saoott*, and *cebagin*.

Sources of Lead Exposure

Occupational lead exposures may occur in the following workers (examples):

Lead mining, refining, smelting, and manufacturing industry employees	Printers	Gas station attendants
Plumbers, pipe fitters	Plastic manufacturers	Battery manufacturers
Auto repairers	Police officers	Bridge reconstruction workers
Glass manufacturers	Steel welders or cutters	Firing range instructors
Shipbuilders	Construction workers	Battery recyclers
	Rubber product manufacturers	

(continued)

Environmental lead exposures to children and adults may also occur (examples):

Lead-containing paint	Soil/dust near lead industries,	Plumbing leachate (from pipes or
Leaded gasoline	roadways, lead-painted homes	solder)
		Ceramic ware

Hobbies and related activities are additional sources of lead exposure (examples):

Glazed pottery-making	Painting	Car or boat repair
Target shooting at firing ranges	Preparing lead shot or fishing sinkers	Home remodeling
Lead soldering (e.g., electronics)	Stained-glass making	

Other potential sources of lead exposure may occur (examples):

Folk remedies	Moonshine whiskey	Tobacco smoking
Cosmetics	Gasoline “huffing”	

Biologic Fate

The absorption and biologic fate of lead once it enters the human body depend on a variety of factors. Especially important determinants are the physiologic characteristics of the exposed person, including nutritional status, health, and age. Children and pregnant women, for example, can absorb up to 70% of ingested lead, whereas adults typically absorb up to 20%. (Most inhaled lead in the lower respiratory tract is absorbed.) The chemical form of lead, or lead compounds, entering the body is also a factor. Organic lead compounds (far rarer since the EPA ban on leaded gasoline additives) are metabolized in the liver, whereas inorganic lead, the most common form of lead, does not undergo such transformation.

Most of the lead that is absorbed into the body is excreted either by the kidney (in urine) or through biliary clearance (ultimately, in the feces). The percentage of lead excreted and the timing of excretion depend on a number of factors. Studies indicate that adults excrete the majority (50%–60%) of an absorbed fraction of lead (when in a steady-state condition with regard to lead intake/output) on a short-term (several weeks) basis, and the vast majority of absorbed lead over time (ATSDR 1999). Adults may ultimately retain only 1% of absorbed lead, but children tend to retain more than adults. In infants from birth to 2 years, approximately one-third of the total amount of lead is absorbed.

Absorbed lead that is not excreted is exchanged primarily among three compartments: blood; soft tissue (liver, kidneys, lungs, brain, spleen, muscles, and heart); and mineralizing tissues (bones and teeth), which typically contain the vast majority of the lead body burden.

Challenge

- (3) *The case study suggests several sources of lead in the boy’s environment. What are these sources? What questions will you ask to gauge the extent of the boy’s exposure to each of these sources? Which of these questions do you think would have been appropriate for the previous pediatrician to ask when the boy was brought in as a 2-year-old?*
 - (4) *What questions will you ask the family to evaluate less obvious, but possible, sources of lead exposure?*
- Once in the bloodstream, lead is primarily distributed among three compartments: blood, soft tissue, and mineralizing tissue. The bones and teeth of adults contain more than 95% of the total lead in the body.

- In times of stress, the body can mobilize lead stores, thereby increasing the level of lead in the blood.

Lead in the Blood

Although the blood generally carries only a small fraction of the total lead body burden, it serves as the initial receptacle of absorbed lead and distributes lead throughout the body, making it available to other tissues (or for excretion). The half-life of lead in adult human blood has been estimated to be from 28 days (Griffin et al. 1975) to 36 days (Rabinowitz et al. 1976). Approximately 99% of the lead in blood is associated with red blood cells (erythrocytes); the remaining 1% resides in blood plasma (DeSilva 1981; EPA 1986a; Everson and Patterson 1980). It is blood plasma, however, which transfers lead between the blood compartment and the soft and mineralizing tissues and which therefore may be more biologically significant. In addition, the higher the lead concentration in the blood, the higher the percentage partitioned to plasma.

Blood lead is also important because the BLL is the most widely used measure of lead exposure. The less-sensitive erythrocyte protoporphyrin (EP) assay is also used as a measure of blood lead. These tests, however, do not measure total body burden: they are more reflective of recent or ongoing exposures (see Laboratory Evaluation for more details).

Lead in Soft Tissues

The blood distributes lead to various organs and tissues. Animal studies indicate that the liver, lungs, and kidneys have the greatest soft-tissue lead concentrations immediately after acute exposure (inhalation, oral, dermal, and intravenous routes) (ATSDR 1999). Of course, the brain is a site of distribution as well. Autopsies of exposed workers revealed that lead had built up in these soft-tissue organs (in decreasing order): liver, kidney, lungs, and brain (Gerhardsson et al. 1995). Studies of the general population have shown that most adult soft tissues (including the brain) do not, however, appear to accumulate lead under standard exposure scenarios as a function of age (Barry 1975, 1981; Gross et al. 1975). As evidenced by levels of retained lead in mineralizing tissue, children retain more lead in soft tissue than do adults. Selective brain accumulation in children and adults may occur in the hippocampus (EPA 1986a). Lead in soft tissues has an approximate half-life of 40 days.

Lead in Mineralizing Tissues (Bones and Teeth)

- The body accumulates lead over a lifetime and normally releases it very slowly.

Most retained lead in the human body is ultimately deposited in bones. The bones and teeth of adults contain about 94% of their total lead body burden; in children the figure is approximately 73% (Barry 1975). Lead in mineralizing tissues is not uniformly distributed; however, it tends to accumulate in bone regions undergoing the most active calcification at the time of exposure. 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 Wittmers, 1992). A new test to measure lead in bone (K x-ray fluorescence [K-XRF]) usually measures lead levels in trabecular bone at the patella or calcaneus and cortical bone at the tibia. However, this test is mostly used for research at the present time.

Two physiologic compartments appear to exist for lead in cortical and trabecular bone, one labile and one essentially inert (ATSDR 1999). The labile component readily exchanges bone lead with the blood, whereas lead in the inert component may be stored for decades (ATSDR 1999). Under certain circumstances, however, this apparently inert lead will leave the bones and reenter the blood and soft-tissue organs. Bone-to-blood lead mobilization increases during periods of pregnancy, lactation, menopause, physiologic stress, chronic disease, hyperthyroidism, kidney disease, broken bones, and advanced age, and is exacerbated by calcium deficiency. 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. Significant drops in a person's BLL may take several months, or sometimes years, even after complete removal from the exposure sources.

Implications of Biologic Fate

The biokinetics of lead—the way it is taken up, distributed, and stored throughout the body, and its dynamic interchange between compartments of the body—help to explain why past and current elevated exposures can lead to adverse health effects. An acute, high exposure to lead can lead to high short-term BLLs and cause symptoms of lead poisoning; yet symptoms or health effects can also appear in the absence of significant current exposure because of the accumulation of lead from past exposures. In most cases, however, toxic BLLs reflect a mixture of current exposure to lead with endogenous contribution from previous exposure. It is extremely important that primary care physicians, as they evaluate a patient with potential lead poisoning, examine potential current and past lead exposures and look for other factors that affect the biokinetics of lead (such as pregnancy or poor nutrition).

Physiologic Effects

Lead serves no useful purpose in the human body, and its presence in the body can lead to toxic effects, regardless of exposure pathway. 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

- Both past and current elevated exposures to lead increase patient risks for lead effects.

Challenge

- (5) *What would likely be revealed by a radiograph of the abdomen or long bones of a lead-exposed child?*
- (6) *Why does the BLL drop only gradually, even with complete removal from the source of exposure?*
- (7) *Several weeks after chelation therapy and removal from the source of exposure, the patient's BLL can sometimes increase again. What is the cause of this rebound phenomenon?*

(including those with sulfhydryl, amine, phosphate, and carboxyl groups) (ATSDR 1999).

- Acute high lead exposure can cause serious physiologic effects, including death or long-term damage to brain function and organ systems.
- Effects of lead exposure vary according to exposure timing and levels, and other factors, and some effects may be latent.

The blood levels at which health effects have been observed are discussed below. It must be emphasized, however, that these levels are constantly being revised as new data are generated, and that, for children, there may be no threshold for developmental effects. Overt clinical symptoms and health effects that come with high exposure levels can be distinguished on an individual basis by the practicing health care provider. However, lack of overt symptoms doesn't mean "no lead poisoning." Lower levels of exposure have been shown, through population studies, to have many subtle health effects. It is important to interdict all lead exposures.

The sections below describe specific physiologic effects associated with major organ systems and functions.

Neurologic Effects

- Lead primarily affects the peripheral and central nervous systems, renal function, blood cells, and the metabolism of vitamin D and calcium. Lead can also cause hypertension, reproductive toxicity, and developmental effects.

The nervous system is the most sensitive target of lead exposure. Fetuses and young children are especially vulnerable to the neurologic effects of lead because their brains and nervous systems are still developing and the blood-brain barrier is incomplete. There may be no lower threshold for some of the adverse neurologic effects of lead in children; some of these effects have been documented at exposure levels once thought to cause no harmful effects ($<10 \mu\text{g}/\text{dL}$) (CDC 1997a). Because otherwise asymptomatic individuals may experience neurologic effects from lead exposure, clinicians should have a high index of suspicion for lead exposure, especially in the case of children.

- Effects in children generally occur at lower BLLs than in adults.

Children

In children, acute exposure to very high levels of lead may produce encephalopathy and its attendant signs (e.g., hyperirritability, ataxia, convulsions, stupor, and coma or death). The BLLs associated with encephalopathy in children vary from study to study, but BLLs of $70\text{--}80 \mu\text{g}/\text{dL}$ or greater appear to indicate a serious risk (ATSDR 1999). Even without encephalopathy symptoms, these levels are associated with increased incidences of lasting neurologic and behavioral damage (ATSDR 1999).

- The developing nervous system of a child can be affected adversely at BLLs of less than $10 \mu\text{g}/\text{dL}$. It is often impossible to determine these effects through clinical examination.

Children suffer other neurologic effects at much lower exposure levels. There is a large body of evidence that associates decrement in intelligence quotient (IQ) performance and other neuropsychologic defects with lead exposure. Some studies have found, for example, that for every $10 \mu\text{g}/\text{dL}$ increase in BLL, children's IQ dropped by four to seven points (Yule et al. 1981; Schroeder et al. 1985; Fulton et al. 1987; Landsdown et al. 1986; Hawk et al. 1986; Winneke et al. 1990). There is also evidence that the probability of ADHD and hearing impairment in children increases with

increasing BLLs, and that lead exposure may disrupt balance and impair peripheral nerve function (ATSDR 1999). These effects may begin at low, more widespread BLLs (at or below 10 µg/dL in some cases), and it may not be possible to detect them on clinical examination.

Some of the neurologic effects of lead in children may persist into adulthood. One study, for example, correlated lead exposure with lower class standing (classroom performance); greater absenteeism; more reading disabilities; and deficits in vocabulary, fine motor skills, reaction time, and hand-eye coordination in young adults more than 10 years after childhood exposure (Needleman et al. 1990).

Adults

There can be a difference in neurologic manifestations or sequelae between an adult exposed to lead as an adult, and an adult exposed as a child when the brain was developing. Childhood neurologic effects, including possibly ADHD, may persist into adulthood. Other than this, many of the neurologic symptoms experienced by children may also be experienced by lead-exposed adults, although the thresholds tend to be higher. Lead encephalopathy may occur at extremely high BLLs, e.g., 460 µg/dL (Kehoe 1961). Precursors of encephalopathy, such as dullness, irritability, poor attention span, muscular tremor, loss of memory, and hallucination, may occur at lower BLLs.

Less severe neurologic and behavioral effects have been documented in lead-exposed workers with BLLs ranging from 40 to 120 µg/dL. These effects include malaise; forgetfulness; irritability; lethargy; impaired concentration; depression and mood changes; increased nervousness; headache; fatigue; impotence; decreased libido; dizziness; weakness; and paresthesia; as well as diminished reaction time, visual motor performance, hand dexterity, IQ scores, and cognitive performance (ATSDR 1999). There is also some evidence that lead exposure may affect adults' postural balance and peripheral nerve function (ATSDR 1997a, 1997b; Arving et al. 1980; Haenninen et al. 1978; Hogstedt et al. 1983; Mantere et al. 1982; Valciukas et al. 1978). Slowed nerve conduction and forearm extensor weakness (wrist drop), as late signs of lead intoxication, are more classic signs in workers chronically exposed to high lead levels.

Renal Effects

Many studies show a strong association between lead exposure and renal effects. Acute, high dose lead-induced impairment of proximal tubular function manifests in aminoaciduria, glycosuria, and hyperphosphaturia (a Fanconi-like syndrome); these effects appear to be reversible (ATSDR 1999). However, continued or repetitive exposures can cause a toxic stress on the kidney that, if unrelieved, may develop into chronic and often irreversible lead nephropathy (i.e., interstitial nephritis).

- There is a wide range of neurologic effects associated with lead exposure, some of which may likely be irreversible.

- Lead exposure can lead to renal effects such as Fanconi-like syndromes, chronic nephropathy, and gout.

- Most lead-associated renal effects or disease are a result of ongoing chronic or current high acute exposure. They can also be attributable to previous chronic lead exposure.

The lowest level at which lead has an adverse effect on the kidney remains unknown. 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). Currently, there are no early and sensitive indicators (e.g., biomarkers) considered predictive or indicative of renal damage from lead, and serum creatinine and creatinine clearance are used as later indicators. However, certain urinary biomarkers of the proximal tubule (e.g., N-acetyl-β-D-glucosaminidase) show elevations with current exposures, even at BLLs less than 60 µg/dL; and some population-based studies show accelerated (i.e., greater than that for normal aging) increases in serum creatinine or decrements in creatinine clearance at BLLs below 60 µg/dL (Staessen et al. 1992; Kim et al. 1996; Payton et al. 1994). Some renal disease or decrement in renal function may be caused by latent effects of lead exposure that occurred years earlier. In children, acute lead-induced renal effects appear reversible, with recovery usually occurring within 2 months of treatment (Chisolm et al. 1976). Treatment of acute lead nephropathy in children appears to prevent progression to chronic interstitial nephritis (Wedeen et al. 1986).

It should be noted that end-stage renal disease is a relatively rare occurrence in the U.S. population. Renal disease can be asymptomatic until the late stages and may not be detected without specific testing. If renal disease is detected and treated early, intervention may slow or stop (but not reverse) progression of renal failure. Because past or ongoing excessive lead exposure may also be a causal agent in kidney disease associated with essential hypertension (ATSDR 1999), primary care providers should especially assess and follow closely the renal functions of persons with hypertension with a past history of lead exposure (see Hypertension Effects). Because renal failure can contribute to the severity of hypertension, and vice versa, can contribute to each other's occurrence and severity, when either health effect presents the other generally should be monitored. Both conditions should be strictly controlled when present. In addition, other known causes of renal disease or damage, such as diabetes mellitus, should be especially well controlled in patients with excess past or current lead exposure.

Lead exposure is also believed to contribute to the onset of "saturnine gout," which may develop as a result of lead-induced hyperuricemia due to decreased renal excretion of uric acid. In one study, more than 50% of patients suffering from lead nephropathy also suffered from gout (Bennett 1985). Saturnine gout is characterized by less frequent attacks than primary gout. Lead-associated gout may occur in premenopausal women, an uncommon occurrence in nonlead-associated gout (Goyer 1985). A study by Batuman et al. (1981) suggests that renal disease is more frequent and more severe when associated with saturnine gout than with primary gout.

Hematologic Effects

Lead inhibits the body's ability to make hemoglobin by interfering with several enzymatic steps in the heme pathway. Specifically, lead decreases heme biosynthesis by inhibiting δ -aminolevulinic acid dehydratase and ferrochelatase activity. Ferrochelatase, which catalyzes the insertion of iron into protoporphyrin IX, is quite sensitive to lead. 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 zinc protoporphyrin [ZPP]—bound to zinc rather than to iron). An increase in blood and plasma δ -aminolevulinic acid and free EPs is also associated with lead exposure (EPA 1986a). EPA estimates that the threshold BLL for a decrease in hemoglobin is 50 $\mu\text{g}/\text{dL}$ for occupationally exposed adults and approximately 40 $\mu\text{g}/\text{dL}$ for children, although other studies have indicated a lower threshold (e.g., 25 $\mu\text{g}/\text{dL}$) for children (EPA 1986b, ATSDR 1999). 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 a screening test as previously thought. (See Laboratory Evaluation for further discussion of EP testing.)

Lead can induce two types of anemia, often accompanied by basophilic stippling of the erythrocytes (ATSDR 1999). Acute, high-level lead exposure has been associated with hemolytic anemia. 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 normocytic or microcytic with associated reticulocytosis. Frank anemia is not an early manifestation of lead exposure and is evident only when the BLL is significantly elevated for prolonged periods.

The heme synthesis pathway (including cytochromes), on which lead has an effect, is involved in many other processes in the body including neural, renal, endocrine, and hepatic pathways. There is a concern about the significance and possible sequelae of these biochemical and enzyme changes at lower levels of lead.

Endocrine Effects

Studies of children with high lead exposure have found that a strong inverse correlation exists between BLLs and vitamin D levels. Lead impedes vitamin D conversion into its hormonal form, 1,25-dihydroxyvitamin D, which is largely responsible for the maintenance of extracellular and intracellular calcium homeostasis; diminished 1,25-dihydroxyvitamin D, in turn, may impair cell growth, maturation, and tooth and bone development. In general, these adverse effects seem to be restricted to children with chronically high BLLs (most significantly in children with BLLs > 62 $\mu\text{g}/\text{dL}$) and chronic nutritional deficiency, especially with regard to calcium, phosphorus, and

- Lead inhibits several enzymes critical to the synthesis of heme, causing a decrease in blood hemoglobin.

- Today, lead exposure in children only rarely results in frank anemia.

- Lead's impairment of heme synthesis can affect other heme-dependent processes in the body outside of the hematopoietic system.

- Lead interferes with a hormonal form of vitamin D, which affects multiple processes in the body, including cell maturation and skeletal growth.

vitamin D (Koo et al. 1991). However, Rosen et al. (1980) noted that in lead-exposed children with blood lead levels of 33–55 µg/dL, 1,25-dihydroxyvitamin D levels were reduced to levels comparable to those observed in children with severe renal insufficiency. Minimizing lead exposure, and assuring sufficient calcium and Vitamin D in the diet throughout all stages of life, can help individual patients to ensure peak bone densities and diminish osteoporosis risk factors (ATSDR 1999, 1997b).

The effects of lead exposure on thyroid function have been examined in occupationally exposed adult workers and in children. Lead appears to have a minimal, if any, effect on thyroid function. A weak negative correlation has been reported between duration of exposure and thyroxin and free thyroxin levels (ATSDR, 1999). This suggests that chronic lead exposure could adversely affect the thyroid over time. No effects of lead on thyroid function have been found in children (ATSDR 1999).

Cardiovascular (Hypertension) Effects

- Lead exposure may lead to increased risk for hypertension and its sequelae.

Hypertension is a complex condition with many causes and risk factors, including older age, increased weight, poor diet and exercise habits, and excess alcohol intake. Lead exposure is one factor of many that may contribute to the onset and development of hypertension. Although low-level lead exposures (BLL < 30 µg/dL) show only a low magnitude of association with hypertension, studies show that greater exposures (primarily occupational) increase the risk for hypertensive heart disease and cerebrovascular disease as latent effects. 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). Several studies support an association between lead exposure and elevations in blood pressure (Victory et al. 1988, Schwartz 1995, Korrick et al. 1999, Hu et al. 1996). The association has been shown in population-based studies with BLLs below 10 µg/dL. Increased odds of hypertension have been associated with the higher (compared to the lower) end of the range of bone lead levels in studies of veterans and nurses unaware of past lead exposure. It is estimated that, on a population mean basis, systolic blood pressure may rise 1–2 mm with each doubling of blood lead, and that blood lead can account for a 1 to 2% variance in blood pressure. On a population basis, this could increase the incidence of hypertension a substantial amount because of the high prevalence of hypertension of all causes in general populations. Because renal failure and hypertension can exacerbate each other, in general when either health effect presents, the other should be monitored (see Renal Effects). Persons with a history of excessive lead exposure should especially strive to follow standard guidelines to limit controllable risk factors for hypertension.

Reproductive and Developmental Effects

Male Reproductive Effects

Recent reproductive function studies in humans suggest that current (ongoing) occupational exposures may decrease sperm count totals and increase abnormal sperm frequencies (Alexander et al. 1996; Gennart et al. 1992; Lerda 1992; Lin et al. 1996; Telisman et al. 2000). Effects may begin at BLLs of 40 µg/dL (ATSDR 1999). Long-term lead exposure (independent of current lead exposure levels) also may diminish sperm concentrations, total sperm counts, and total sperm motility (Alexander et al. 1996). It is unclear how long reproductive effects may last in humans after lead exposure ceases.

- Evidence suggests an association between lead exposure and certain reproductive and developmental outcomes.

Fertility

Although a few studies have investigated lead's possible effect on male fertility, results are contradictory and there is at present no body of evidence to address this question. Whether and how lead exposure may affect female fertility remains an even more open question. Many factors can affect female fertility. It is not currently possible to predict fertility outcomes based on current BLLs or past lead exposure levels. A health care provider should approach the work-up and treatment of infertility in a standard fashion whether the patient has a history of lead exposure or not. Persons previously exposed to excessive lead should control those infertility risk factors that they can (e.g., alcohol and reproductive system infections).

Pregnancy Outcomes

An increased frequency of miscarriages and stillbirths among women working in the lead trades was reported as early as the turn of the century. Although the data concerning exposure levels are incomplete, these effects were probably a result of far greater exposures than are currently found in lead industries. The effect of low-level lead exposures on pregnancy outcomes is not clear. Some studies of women living near smelters versus those living some distance away did show increased frequency of spontaneous abortions (Nordstrom et al. 1979) and miscarriages and stillbirths (Baghurst et al. 1987; McMichael et al. 1986). In contrast, Murphy et al. (1990) evaluated past pregnancy outcomes among women living in the vicinity of a lead smelter and did not find an increase in spontaneous abortion risk among the lead-exposed group versus the unexposed group. Results of another recent retrospective study indicate that women who experienced overt childhood lead poisoning 50 years earlier may have also experienced a higher rate of spontaneous abortions and miscarriages (Hu 1991).

Thus there appears to be an association between higher (e.g., occupational) lead exposure levels and adverse pregnancy outcomes. This association becomes equivocal when looking at women exposed to lower environmental levels of lead.

- Maternal blood lead, from exogenous and endogenous sources, can cross the placenta and put the fetus at risk.

Developmental Effects

Developmental effects examined in the literature include pregnancy issues (e.g., premature births and low birth weights), congenital abnormalities, and postbirth effects on growth or neurologic development. Increasing evidence indicates that lead, which readily crosses the placenta, adversely affects fetus viability as well as fetal and early childhood development. 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 1999).

Although lead is an animal teratogen, most human studies have not shown a relationship between lead levels and congenital malformations. A study by Needleman et al. (1984) correlated increased prenatal lead exposure with increased risk for minor congenital abnormalities (e.g., minor skin abnormalities and undescended testicles). An association between prenatal lead exposure and major congenital abnormalities appears nonexistent (Ernhart et al. 1985, 1986; McMichael et al. 1986). In a retrospective study (see Pregnancy Outcomes), a higher proportion of learning disabilities was found among school-aged children with biological parents who were lead poisoned as children 50 years previously (Hu 1991). This suggests that the children of parents who experienced overt lead poisoning as children could be at greater risk for neurologic development impairment (Hu 1991).

Carcinogenic Effects

- EPA's Science Advisory Board has recommended that lead be considered a probable human carcinogen.

Challenge

- (8) *What are the major effects of lead on the human body?*
- (9) *How do lead's effects differ in children and adults?*
- (10) *Why is physical examination alone often not enough to determine whether or not a child is experiencing potentially harmful lead exposure?*

Current available data are not sufficient to determine the carcinogenicity of lead in humans. EPA classified elemental lead and inorganic lead compounds as Group 2B: probable human carcinogens (ATSDR 1999). This classification is based in part on animal studies, which have been criticized because the doses of lead administered were extremely high (ATSDR 1999). The National Toxicology Program classifies lead acetate and lead phosphate as "may reasonably be anticipated to be carcinogens." Information regarding the association of occupational exposure to lead with increased cancer risk is generally limited in its usefulness because the actual compound of lead, the route of exposure, and level of lead to which the workers were exposed were often not reported. In addition, these occupational exposure studies, which primarily examined lead smelters, involved confounding exposures to other chemicals, including arsenic, cadmium, antimony, and toxicants from worker smoking habits (Cooper 1976 and IARC 1987).

Clinical Evaluation

Preventive Assessment and Screening

It is often possible and many times crucial for a primary care provider to identify individuals who may have been exposed to potentially dangerous

levels of lead, to test (screen) them appropriately, clinically manage them, and facilitate appropriate environmental and nutritional intervention before symptoms of lead poisoning manifest themselves. Often the recognition of a lead exposure problem and implementation of the system of interventions that is set up between government agencies such as the state and local health departments and the Department of Housing and Urban Development depend on the initial reporting of high BLLs by primary care providers.

In the case of children, CDC recommends that states develop statewide plans for BLL screening (CDC 1997a). These plans may advocate universal screening of children from high-risk areas at ages 1 or 2 and of all children up to age 7 who have not previously been screened. For example, if 12% or more children in a given community have BLLs $\geq 10 \mu\text{g/dL}$, or if 27% or more of the housing stock is pre-1950, CDC recommends universal screening (see Standards and Regulations). Alternatively, statewide plans may call for targeted screening based on responses to several questions intended to determine risk more selectively (e.g., type and age of house and whether or not patient's family members are Medicaid recipients). Contact your state or local health department to see if your state has a lead-screening plan. If your pediatric patient falls into a category such as Medicaid recipient where screening is required or recommended, it is important to follow the guidelines and screen the patient. It is equally important to report a positive test to the appropriate agency or agencies. For occupationally exposed adults, consult the federal lead standard for the mandated type and frequency of lead screening (see Standards and Regulations: Workplace Air). (Note: BLLs for medical surveillance may be done at work as part of Occupational Safety and Health [OSHA] regulations. However, when evaluating the patient, the primary care provider should assess whether a patient fits into an occupational group exposed to lead and whether the BLL is being monitored.)

In the absence of health department guidance on screening, the first step in identifying individuals with potential lead exposure is to determine through appropriate questioning whether or not any of the typical lead exposure pathways are cause for heightened concern. (In the case study, the fact that the previous pediatrician apparently did not pursue this line of questioning constitutes a missed opportunity for preventive action.) Many health departments can provide physicians with personal risk questionnaires and/or localized risk information to help in this process (see Sources of Information). Here are some of the issues a physician might discuss with the patient and/or family (see also *Case Studies in Environmental Medicine: Taking an Exposure History*):

- location, age, and physical condition of current residence, school, day-care center, etc. (to identify potential for lead paint as well as proximity

- Because children may be exposed to potentially adverse levels of lead without exhibiting clinical symptoms, it is vital that primary care providers adopt a preventive approach to determine which of their patients may be at risk.

- Primary care providers can adopt a preventive approach by asking questions to assess a patient's potential for exposure to lead and/or by following statewide protocols for screening. Where the potential for exposure exists, a patient's BLL should be tested.

to industrial facilities, hazardous waste sites, and other potential lead sources)

- frequency of visits to houses or facilities built before 1950
- home remodeling activities
- past living conditions (international background is important)
- occupational history of all home occupants
- family history, including possibility of maternal/family exposure and potential use of unusual medicines or home remedies
- condition of household pets
- hobbies of all family members
- use of imported or glazed ceramics
- drinking water source and type of pipe
- nutritional status
- siblings or playmates who have been diagnosed with lead poisoning.

Lead is most harmful to children under 6 years of age. Every child who has a developmental delay, behavioral disorder, or speech impairment, or who may have been exposed to lead should be screened. Equally important, siblings, housemates, and playmates of children with suspected lead toxicity have probably had similar exposures to lead and should be screened.

Individuals with potentially high lead exposure should be screened with a blood lead test. They (and/or their parents) should also receive lead education, including guidance on appropriate nutritional, behavioral, and environmental interventions (see Treatment and Management). Physicians may want to consider giving parents anticipatory guidance prenatally and before a child reaches 1 year of age. Physicians should take advantage of the programs and printed materials available through state and/or local health departments in providing this guidance.

Physical Examination

- Although it is important for monitoring the effects of lead exposure and, in some cases, for identifying the symptoms of lead poisoning, the physical examination alone will not always reveal when a patient is at risk from elevated lead exposure.

In addition to the environmental and family history assessment and BLL screening, physicians should conduct a complete physical examination of patients with potential exposure to lead. It is important to keep in mind, however, that even a complete physical examination may not identify subtle neurologic effects that may be associated with low-level lead exposure in children.

The physical examination should include special attention to the neurologic, hematologic, cardiovascular, gastrointestinal, and renal systems. The health care provider should be certain to check blood pressure to evaluate whether

the patient is hypertensive, and should pay special attention to the renal system in those who are hypertensive. The nervous system, including behavioral changes, should be carefully evaluated. A purplish line on the gums (lead line) is rarely seen today, but if present, is usually indicates severe and prolonged lead poisoning.

For children, hearing, speech, and other developmental milestones should be carefully evaluated and documented. When the neurologic exam, milestones, or behavior suggest it, further neurobehavioral testing, or evaluation for ADHD, may be indicated. The opening case study illustrates a second missed opportunity: Despite the delayed growth (20th percentile) and speech indicators discovered during the preschool physical (at age 4), no BLL test was ordered at that time.

Because iron and calcium deficiencies enhance the absorption of lead and aggravate the tendency to pica behaviors, it is especially important to assess the nutritional status of young children.

Signs and Symptoms

Because of differences in individual susceptibility, symptoms of lead exposure and their onset may vary. Frequently, lead exposure appears asymptomatic, but may still impair the health of children and adults. With increasing exposure, the severity of symptoms can be expected to increase. The impaired abilities that may be associated with lead exposure in an apparently asymptomatic patient are listed below, as are overt symptoms of lead toxicity associated with ongoing exposure. The impaired abilities may occur at BLLs ranging from 10 to 25 $\mu\text{g}/\text{dL}$, whereas in symptomatic lead intoxication, BLLs generally range from 35 to 50 $\mu\text{g}/\text{dL}$ in children and 40 to 60 $\mu\text{g}/\text{dL}$ in adults. Severe toxicity is frequently found in association with BLLs of 70 $\mu\text{g}/\text{dL}$ or more in children and 100 $\mu\text{g}/\text{dL}$ or more in adults. Keep in mind that dividing the symptoms into mild, moderate, and severe is somewhat artificial—the signs and symptoms generally go from mild to severe with increasing BLL but in individuals may appear at variance with these designations. The importance for the clinician is to recognize ongoing lead exposure, interdict that exposure, and treat the patient as appropriate.

Some of the hematologic signs of lead poisoning mimic other diseases or conditions. In the differential diagnosis of microcytic anemia, lead poisoning can usually be ruled out by obtaining a venous blood lead concentration; if the BLL is less than 25 $\mu\text{g}/\text{dL}$, the anemia usually reflects iron deficiency or hemoglobinopathy. Two rare diseases, acute intermittent porphyria and coproporphyrin, also result in heme abnormalities similar to those of lead poisoning.

Other effects of lead exposure can be misleading. Patients exhibiting neurologic signs due to lead exposure have been treated only for peripheral

- The first signs of lead toxicity in children are often subtle neurobehavioral problems that adversely affect classroom behavior and social interaction.
- Developmental, speech, and hearing impairments are not uncommon in lead-exposed children (ATSDR 1999).

- Most persons with lead toxicity are not overtly symptomatic.

neuropathy or carpal tunnel syndrome, delaying treatment for lead intoxication. Failure to correctly diagnose lead-induced gastrointestinal distress has led to inappropriate abdominal surgery.

- Some of the health effects of lead exposure on the various organ systems (see Physiologic Effects) are permanent or latent and may appear after exposure has ceased.
- Current exposure is not required for health effects that may need intervention. Current health effects (e.g., neurologic/developmental) resulting from past exposure may also need intervention. For example, special education or intervention may be needed to prevent recurrent exposure, if the danger of exposure is still present. Others besides the patient could also be at risk for exposure, and could benefit from the intervention.

Continuum of Signs and Symptoms Associated With Toxicity of Ongoing Lead Exposure

Impaired Abilities (Patient May Appear Asymptomatic)

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

Mild Toxicity

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

Moderate Toxicity

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

Severe Toxicity

- Paresis or paralysis
- Encephalopathy—may abruptly lead to seizures, changes in consciousness, coma, and death
- Lead line (blue-black) on gingival tissue
- Colic (intermittent, severe abdominal cramps)

Laboratory Evaluation

Laboratory tests used to evaluate lead exposure include the BLL and EP assays. Several other tests have been used in the past to evaluate and gauge the effects of lead exposure, but they are less commonly used now.

BLL

- The best screening and diagnostic tool for evaluating lead exposure is the BLL test.
- Venous BLL testing is the most useful screening and diagnostic test for recent or ongoing lead exposure. Given the greater risk of skin contamination using the finger-stick method, an elevated BLL obtained through finger-sticking should always be confirmed through venipuncture (American Academy of Pediatrics 1993; CDC 1997a).

BLLs respond relatively rapidly to abrupt or intermittent changes in lead intake (for example, ingestion of lead 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 and may be found at “normal” levels in the blood. (One exception is patients with a high body burden under stressful circumstances, whose BLLs may be elevated from the release of lead stored in bones.) New technologies, such as K-XRF, are being developed to measure lead content of bone. However, they are used presently for research and are not widely available to the clinician.

The average BLL for children 1–5 years of age was 2.7 $\mu\text{g}/\text{dL}$ in 1991–1994, down from 15.0 $\mu\text{g}/\text{dL}$ in 1976–1980 (before leaded gasoline was banned; CDC 1997a). The average BLL for adults 18–74 years of age was 14.2 $\mu\text{g}/\text{dL}$ from 1976–1970; in 1988–1991, the average BLL for adults was 3.0 $\mu\text{g}/\text{dL}$ (CDC 1997b). However, levels of concern for lead exposure have also been progressively declining as more sensitive analyses and measures are developed (see Standards and Regulations: Biologic Guidelines). CDC currently considers children to have an elevated level of lead if their BLL is 10 $\mu\text{g}/\text{dL}$ or higher. For adults in the workplace, OSHA considers an average BLL of 50 $\mu\text{g}/\text{dL}$ as cause for removal from the job and a BLL of 40 $\mu\text{g}/\text{dL}$ as cause for mandatory notification. However, this is the recommendation for workers, not the general public. Some states have lower levels of concern for adults: for example, 25 $\mu\text{g}/\text{dL}$ in Washington State. An attempt should be made to identify and minimize lead exposures when BLLs indicate that they are occurring, even at exposures below these levels. If an adult has a BLL of 20 $\mu\text{g}/\text{dL}$, e.g., an exposure is likely occurring and should be halted, if possible. This is especially important for fertile and pregnant females. For treatment guidelines based on BLL results, see Treatment and Management.

BLL screening may be appropriate for children and, under certain circumstances, for adults. For more information about when screening is appropriate, see Preventive Assessment and Screening and Standards and Regulations.

EP and ZPP Levels

EP, commonly assayed as ZPP, was once the test of choice for screening asymptomatic children and other populations at risk. Recent data indicate that the EP/ZPP assay, however, is not sufficiently sensitive at lower BLLs and therefore is not as useful a screening test for lead exposure as previously thought. Also, in contrast to BLL testing, these assays are not specific to lead and they have a lag time (approximately 120 days) before showing effects of an exposure. The mean half life of ZPP is 68 days, and the

- Using an EP or ZPP assay to screen children for lead exposure is not as useful as once thought.

baseline level is approximately 36 $\mu\text{g}/\text{dL}$ (Hryhirczuk et al. 1985). EP/ZPP assays continue to be used occasionally as a complement to BLL testing.

The EP/ZPP assays indicate elevated levels of protoporphyrin in the blood due to substitution of zinc for iron in the porphyrin moiety (which in turn results from lead's inhibition of the mitochondrial enzyme ferrochelatase—see Physiologic Effects for more detail). Protoporphyrin reaches a steady state in the blood only after the entire population of circulating erythrocytes has turned over, which takes about 120 days, and protoporphyrin also has a longer half-life (68 days; Hryhirczuk et al. 1985) than blood lead (28–36 days; ATSDR 1999). Consequently, the assays are indirect measures of intermediate exposure to lead.

Normal values of ZPP are usually below 35 $\mu\text{g}/\text{dL}$. Increased EP concentrations, however, are proportional (after the time lag) to BLL levels only over the range of 30–80 $\mu\text{g}/\text{dL}$ (Porru and Alessio 1996). Thus the EP/ZPP test is not sensitive enough to identify lead exposure at lower BLL levels, and it could result in false negatives.

EP is also elevated in jaundice and in iron deficiency anemia and sickle cell and other hemolytic anemias. In erythropoietic protoporphyria, an extremely rare disease, EP is markedly elevated (usually above 300 $\mu\text{g}/\text{dL}$).

Challenge

- (11) *What steps can a physician take that are of greater or equal importance to a physical examination in determining a patient's potential exposure to lead?*
- (12) *What should be included in the problem list for the patient described in the case study?*
- (13) *List several possible causes of the boy's anemia.*
- (14) *You drew a ZPP first and have just learned from the laboratory that the boy has a ZPP level of 350 $\mu\text{g}/\text{dL}$. What are the possible causes of this elevated value?*
- (15) *What other laboratory tests will you now order to confirm or rule out your diagnosis?*

Other Evaluation Methods

Other methods to evaluate lead exposure include the complete blood count (CBC) with peripheral smear, abdominal radiographs, and hair and fingernail assays. In lead-exposed patients, the hemocrit 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. A hypochromic, microcytic anemia should be appropriately differentiated from other causes, especially iron-deficiency anemia.

Abdominal radiographs are helpful only in cases of acute ingestion (e.g., of lead sinkers, curtain weights, or paint chips) or unusual persistence of high blood lead values. 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 (American Academy of Pediatrics 1993).

Evaluation may also appropriately include tests for the health effects of lead. For example, blood urea nitrogen, creatinine, and urinalysis reveal only late significant effects of lead on renal function. These tests are not specific for

lead, but can also identify other renal disease (hypertensive, diabetic) that the (previously) lead-exposed patient should keep especially well controlled. Renal urinary biomarkers are an advancing field, but currently there are no urinary biomarkers acceptable as specific for early detection of lead nephropathy. However, some hold promise in settings of surveillance for early effects of current lead exposure (e.g., in occupational settings). In addition, second-tier tests (such as neurobehavioral/psychologic evaluation for children with indicative findings on exam) should be considered, as appropriate.

Treatment and Management

Clinical Management

Table 1 provides treatment guidance for children according to BLL based on CDC recommendations (CDC 1997a).

Most of the treatment actions listed in Table 1 are described in the bullets below.

- Lead education and referrals: Patients with elevated BLLs, and their families, should receive education about the potential health effects of lead exposure, important environmental and behavioral interventions to reduce potential for lead exposure, and the importance of good nutrition in reducing the absorption and effects of lead. Health departments can often furnish educational materials to health-care providers, and many times have an established program for education and coordination of care (case management). In some cases, physicians may want to refer patients to appropriate social services providers (e.g., for learning assistance if the child is falling behind in school) and even, in more extreme cases, to physicians with experience in treating lead poisoning. Appropriate clinical referrals should also be made for lead's health outcomes based on a positive clinical exam and/or positive tests (such as second-tier neurobehavioral tests, which may also require a referral for diagnosis) if specialty consultation is needed.
- Diagnostic testing: Diagnostic testing refers to collecting and analyzing a venous blood sample to confirm a capillary blood screening test, before acting on the result. A venous BLL is a follow-up test to monitor the status of a child with an elevated diagnostic BLL, to ensure that the elevated BLL is not continuing or rising.
- Clinical evaluation and management: Clinical management means that the care should be provided by a health care provider and include the evaluation, family lead education and referrals, chelation therapy as
 - There is a continuum of options—including education, aggressive environmental intervention, and, for more extreme cases, chelation therapy—available to treat patients with elevated BLLs ($\geq 10 \mu\text{g}/\text{dL}$). Selection of treatment options depends largely on a patient's BLL and physical exam.
 - For the majority of lead-exposed patients, some combination of lead education, aggressive environmental intervention, clinical management, and continued monitoring is indicated. Chelation therapy is only indicated in patients with extremely high or high and persistent BLLs.

- All elevated BLL tests should be reported to the local or state health department as required in the particular state, and the health care provider should also coordinate with the health department in case management.

appropriate (see below), and follow-up testing at appropriate intervals. The evaluation should include a medical history (focusing on developmental progress in the case of children), environmental history, nutritional history, evaluation of child’s iron status, and a physical examination, to include complications of lead toxicity.

Table 1. Guidance for Treatment Actions According to Blood Lead Level (BLL)

BLL (µg/dL*)	Treatment Actions
10–19	<p>Provide lead education and referrals</p> <p>Provide diagnostic testing within 3 months and follow-up testing within 2 to 3 months</p> <p>Proceed according to guidelines in 20–44 µg/dL range if BLLs persist in 15–19 µg/dL range</p> <p>(The presence of a large proportion of children in the 10–14 µg/dL range should trigger community-wide lead poisoning prevention.)</p>
20–44	<p>Provide lead education and referrals</p> <p>Provide coordination of care (case management)</p> <p>Perform clinical evaluation and management</p> <p>Provide diagnostic testing (from within 1 month to within 1 week) and follow-up testing (every 1 to 2 months)</p> <p>Perform aggressive environmental intervention</p>
45–69	<p>Provide lead education and referrals</p> <p>Provide coordination of care (case management) within 48 hours</p> <p>Perform clinical evaluation and management within 48 hours</p> <p>Provide diagnostic testing within 24–48 hours and follow-up testing (in accordance with chelation therapy, at least once a month)</p> <p>Perform aggressive environmental intervention</p> <p>Provide appropriate chelation therapy</p>
≥70†	<p>This is a medical emergency</p> <p>Perform diagnostic testing immediately as an emergency laboratory test</p> <p>Hospitalize and begin immediate chelation therapy</p> <p>Begin other activities as above</p>

*µg/dL: micrograms per deciliter.

†Or in case of encephalopathy.

- **Aggressive environmental intervention.** Aggressive environmental intervention refers to investigating potential lead exposure pathways and taking immediate steps to control the actual lead hazards identified. If exposure is severe enough, immediate separation from the source (such as relocation from housing with lead-based paint) is indicated. For less severe exposure, for example, if lead paint is a major exposure pathway, immediate interim steps such as damp mopping and covering old paint can be taken before long-term measures (e.g., moving out of or deleading the house) are implemented. *Environmental intervention should be coordinated through the state or local health department, which is likely to have the best resources and expertise for coordination or support.*
- **Chelation therapy:** Chelating agents are drugs that bind with heavy metals in the bloodstream, causing them to be discharged from the body in urine and bile. Chelation therapy can be effective at reducing the total lead body burden (and acute toxicity effects) in individuals with high current BLLs, but it is generally not indicated for individuals with BLLs below 45 µg/dL. Because of the risk of potential harmful effects of the chelating agents and the remobilized lead, chelation therapy is also not recommended for those persons with high past exposures to lead and low BLLs who wish to remove lead from their bodies. Instead, a calcium-rich diet or supplements might be recommended, if not contraindicated, to prevent calcium deficiency and subsequent release of lead from the bones. Chelation therapy should always be accompanied by aggressive environmental intervention, and the patient should not be returned to the same environmental exposure situation unless a correction (e.g., interdiction, remediation) is implemented. The four chelating agents commonly used in treating patients with high BLLs or signs of encephalopathy are shown in Table 2.

Because there are potential side effects associated with each 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

Product Name	Generic Name	Chemical Name	Abbreviation
Calcium disodium versenate	Edetate disodium calcium	Calcium disodium ethylenediaminetetraacetate	CaNa ₂ EDTA
British anti-Lewisite (BAL) in oil	Dimercaprol	2,3-Dimercaptopropanol	BAL
Cuprimine	D-Penicillamine	3-Mercapto-D-valine	D-Penicillamine
Chemet	Succimer	Meso-2,3-dimercaptosuccinic acid	DMSA

Challenge

- (16) *What can you as a physician do to prevent a patient's exposure to lead?*
- (17) *The laboratory results indicate that the BLL of the child in the case study is 50 µg/dL. What treatment and follow-up activities will you recommend?*
- (18) *Who should you contact for medical consultation regarding this boy's case?*

begun (American Academy of Pediatrics 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 calcium disodium versenate mobilization (challenge) test is no longer recommended because of its difficulty, expense, and potential for increasing lead toxicity (American Academy of Pediatrics 1995).

Standards and Regulations

Because of lead's importance as a cause of public health problems, a number of federal agencies have issued advisory standards or enforceable regulations that set lead levels in different media. Table 3 summarizes these standards and regulations; see subsequent sections for further explanation.

Table 3. Summary of Standards and Regulations for Lead

Agency	Media	Level	Comments
Centers for Disease Control and Prevention	Blood	10 µg/dL*	Advisory; level of concern for children
Occupational Safety and Health Administration	Blood	40 µg/dL	Regulation; cause for written notification and medical exam
		50 µg/dL	Regulation; cause for medical removal from exposure
	Air (workplace)	50 µg/m ^{3†}	Regulation; permissible exposure limit (8-hr average) (general industry)
		30 µg/m ³	Regulation; action level
National Institute for Occupational Safety and Health	Air (workplace)	50 µg/m ³	Advisory; recommended exposure limit (nonenforceable)
		100 mg/m ³	Advisory; immediately dangerous to life and health
American Conference of Governmental Industrial Hygienists	Air (workplace)	150 µg/m ³	TLV/TWA‡ guideline for lead arsenate
	Blood	50 µg lead/m ³ 30 µg/dL	TLV/TWA guideline for other forms of lead Advisory; biological exposure index
U.S. Environmental Protection Agency	Air (ambient)	1.5 µg/m ³	Regulation; National Ambient Air Quality Standard; 3-month average
	Soil (residential)	400 mg/kg	Soil screening guidance
	Water (drinking)	15 µg/L 0 µg/L	Action level for public supplies Nonenforceable goal; maximum contaminant level goal
Food and Drug Administration	Food	Various	Action levels for various foods; example: lead-soldered food cans now banned
Consumer Product Safety Commission	Paint	600 ppm§ (0.06%)	Regulation; by dry weight

*µg/dL: micrograms per deciliter.

†µg/m³: micrograms per cubic meter.

‡TLV/TWA: threshold limit value/time-weighted average.

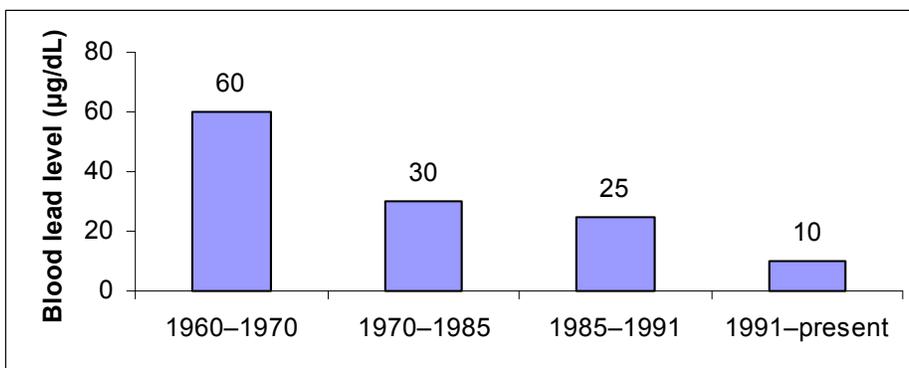
§ppm: parts per million.

Biologic Guidelines

As new information has emerged about the neurologic, reproductive and developmental, and possible hypertensive toxicity of lead, and as more sensitive parameters are developed, the BLLs of concern for lead exposure have been progressively lowered by CDC (see Figure 1). Although the evidence is not definitive, several studies have demonstrated neurobehavioral impairment in lead-exposed children with BLLs as low as 10 to 14 $\mu\text{g}/\text{dL}$ (ATSDR 1999), and there may not be a threshold. If 12% or more children in a given community have BLLs greater than or equal to 10 $\mu\text{g}/\text{dL}$ (or if 27% or more of the housing stock is built before 1950), CDC recommends universal screening, and community-wide interventions should be considered by the appropriate agencies (CDC 1997a). There are also requirements that children receiving Medicaid be screened. Many times all of these conditions merge in inner-city environments.

States may also set levels of concern for children and adults. For example, in Washington State, the level of concern for adults is 25 $\mu\text{g}/\text{dL}$.

Figure 1. Lowering of the Centers for Disease Control and Prevention Recommended Action Level for Blood Lead in Children



Physician Reporting Requirements

Most states ask or require primary care physicians and persons in charge of screening programs to report both presumptive and confirmed cases of lead toxicity to the appropriate health agency so that abatement of the lead source, education of the patient, and remediation steps can be undertaken. Even if not required, a physician should strongly consider consulting a health agency when encountering lead toxicity, because health agencies are important sources of resources and information. In some states, laboratories performing BLL or EP (ZPP) tests are also required to report abnormal results to the appropriate health agency.

- In 1991, CDC lowered the recommended blood lead action level for lead exposure in children to 10 $\mu\text{g}/\text{dL}$.
- States may also set levels of concern for adults and children.
- Most states have reporting systems for lead poisoning.

- OSHA has set required standards for the amount of lead allowed in workroom air at $50 \mu\text{g}/\text{m}^3$ averaged over an 8-hour workday.

Workplace Air

The federal occupational lead standard (EPA 1991) specifies the permissible exposure limit (PEL) of lead in the workplace, the frequency and extent of medical monitoring, and other responsibilities of the employer. The Occupational Safety and Health Administration (OSHA) has set a PEL (enforceable) of lead in workplace air at $50 \mu\text{g}/\text{m}^3$ averaged over an 8-hour workday for workers in general industry. For those exposed to air concentrations at or above the action level of $30 \mu\text{g}/\text{m}^3$ for more than 30 days per year, OSHA mandates periodic determination of BLLs. If a BLL is greater than $40 \mu\text{g}/\text{dL}$, the worker must be notified in writing and provided a medical examination. If a worker's one-time BLL reaches $60 \mu\text{g}/\text{dL}$ (or averages $50 \mu\text{g}/\text{dL}$ or more), the employer is obligated to remove the employee from excessive exposure, with maintenance of seniority and pay, until the employee's BLL falls below $40 \mu\text{g}/\text{dL}$. A copy of the lead standard can be obtained by calling your regional OSHA office or visiting the OSHA Web site (<http://www.osha.gov/>).

The National Institute for Occupational Safety and Health, CDC, has set a recommended exposure limit of $50 \mu\text{g}/\text{m}^3$ to be maintained so that worker blood lead remains less than $60 \mu\text{g}/\text{dL}$ of whole blood. The American Conference of Government Industrial Hygienists has set a threshold limit value for a time-weighted average (TLV/TWA) of $50 \mu\text{g}/\text{m}^3$ for lead in workplace air (except for lead arsenate). The TLV/TWA guideline represents the average concentration to which most workers may be exposed without adverse effects.

Ambient Air

- EPA has set an ambient air standard for lead of $1.5 \mu\text{g}/\text{m}^3$ averaged over a calendar quarter.

Environmental limits are set to protect the most susceptible persons in the general population (as opposed to occupational exposure limits, which generally accommodate healthy adults working 8-hour days). EPA has set a National Ambient Air Quality Standard for lead of $1.5 \mu\text{g}/\text{m}^3$ averaged over a calendar quarter. EPA regulations also ban the use of leaded fuel additives in fuel sold for motor vehicle transport. (By definition, unleaded gasoline can have up to 0.05 grams per gallon of lead, considered a trace amount by EPA.)

Soil

- EPA has established $400 \text{ mg}/\text{kg}$ for lead in residential soils as a guidance value that would be protective of public health.

Uncontaminated soil contains lead concentrations of less than 50 ppm, but soil lead levels in many urban areas exceed 200 ppm (American Academy of Pediatrics 1993). Contaminated areas (e.g., from industry or mine releases) can contain much higher levels. The soil screening level for lead represents a conservative estimate for a residential soil level that would be protective of

public health based on an analysis of the direct ingestion pathway for children. This value is for guidance only and is not enforceable.

Drinking Water

EPA is required to set drinking water standards with two levels of protection. The primary standards define contaminant levels as those above which the water source requires treatment. These maximum contaminant levels (MCLs) are limits enforceable by law and are set as close as possible to the maximum contaminant level goals (MCLGs), the levels determined to be safe by toxicologic and biomedical considerations, independent of feasibility. EPA's final rule for lead does not establish an MCL; the MCLG is zero, and an action level is set at 15 µg/L. If more than 10% of targeted tap water samples exceed the action level, certain actions are required of water system administrators. For further information, call the EPA Safe Drinking Water Hotline toll-free at 1-800-426-4791.

The use of lead solder and other lead-containing materials in connecting household plumbing to public water supplies was banned by EPA as of June 1988. Many older structures, however, still have lead pipe or lead-soldered internal plumbing, which may substantially increase the lead content of water at the tap. Regulations controlling the lead content of drinking-water coolers in schools went into effect in 1989.

Food

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. For example, FDA has set an action level of 0.5 µg/mL for lead in products intended for use by infants and children and has banned the use of lead-soldered food cans (FDA 1994, 1995).

Paint

Before 1955, much white house paint was 50% lead and 50% linseed oil. In 1955, manufacturers adopted a voluntary house paint lead-content standard of 1%, but this was not required until 1971. Since 1977, the Consumer Product Safety Commission has limited the lead in most paints to 0.06% (600 ppm by dry weight). Paint for bridges and marine use may contain greater amounts of lead. Some of these nonresidential paints containing greater lead concentrations may still be used on a limited basis by some individuals for residential purposes.

- EPA's action level for lead in water delivered to users of public drinking water systems is 15 µg/L. Its goal for lead is zero.

- FDA has set various action levels regarding lead in food items. The use of lead-soldered food cans is now banned.

- Today, paint intended for residential use is limited to 0.06% lead content.

Challenge

(19) *Given the facts reported in the case study, including the BLL of 50 µg/dL, should public health authorities or regulatory agencies be notified? Why?*

(20) *You learn from the boy's mother that her place of employment had poor ventilation and no provision for respiratory protection, shower facilities, or work clothes. She ate lunch and smoked in the repair shop. "In fact," she says, "I wonder if my layoff has anything to do with the blood test the company had me get." The company's test indicated that her BLL was 62 µg/dL. What advice could you give the boy's mother regarding her former employment?*

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Answers to Pretest and Challenge Questions

Pretest

- (a) See answers to Challenge question (3) below.
- (b) See answers to Challenge question (12) below.
- (c) See answers to Challenge question (13) below.
- (d) See answers to Challenge question (15) below.

Challenge

- (1) All members of the family are at risk; they should be promptly evaluated and, if necessary, treated. The mother's unborn child is also at risk. Workers in the radiator repair shop and their families, and any of the children's playmates who have accompanied them to the repair shop after school, should also be screened.
- (2) The boy's mother is 5 months pregnant. Because the placenta presents no barrier to lead, the fetus' blood lead level is likely to be similar to that of the mother. It is during the initial weeks of pregnancy that the neurologic system of the conceptus is formed; therefore, damage to the fetus may have already occurred. The mother is no longer working at the repair shop, but you should alert her and the family to the possibility of continued lead exposure via the grandfather, who may be bringing lead dust home on his skin, shoes, or clothes.
- (3) 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. To get a preliminary sense of the potential extent of this exposure pathway, you can ask questions about the age of the family's house, when it was most recently painted, and the condition of the paint. You should determine if the boy ever had pica (a compulsive eating of nonfood items, to be distinguished from normal hand-to-mouth behavior of children). Pica is more common in children aged 2 to 5, so it is unlikely 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. The previous pediatrician would have done a better job if he or she had asked about the condition of the boy's primary residence as well as the occupations of the mother and father.
- (4) To evaluate less obvious, but possible, sources of lead exposure, you might inquire about the proximity of the child's home and play areas to freeways, hazardous waste sites, and industry. The occupations of all adults in the household are important; children of lead-exposed workers have higher lead levels than control groups. You might ask if any of the boy's associates or family members (including the father) have hobbies involving lead, such as those mentioned under Sources of Lead Exposure. You might also inquire whether the home is undergoing remodeling, whether any home or folk remedies are used, if glazed ceramic ware is used for food, or if there are lead or lead-soldered pipes that could contaminate the drinking water in the house.
- (5) If a child does not have pica and there is nothing to suggest that a lead-containing object has recently been ingested, an abdominal radiograph will likely be negative. On long-bone radiograms, opacities in the metaphyseal

plates may be seen after 4–8 weeks or more of lead exposure. These lead lines (which are due to dense zones of calcium and not deposited lead) are more likely to be found in larger bones (e.g., radius and tibia) than in smaller bones (e.g., ulna and fibula). Lead lines seen in the smaller bones may be indicative of a longer exposure, usually across several months. Radiographs are helpful only in the rare circumstances that they are positive. Negative radiographs do not rule out lead poisoning.

(6) Even with complete removal from the source of exposure, the blood lead level will drop only gradually because without chelation, lead is only slowly excreted. In addition, even as lead is excreted, it may be replaced by lead currently stored in bones and teeth.

(7) This rebound phenomenon is due to the mobilization of lead from the body's stores in bones and teeth.

(8) The major effects of lead on the human body are hypertension and damage to the neurologic, hematologic, renal, and reproductive systems.

(9) Because of an incompletely developed blood-brain barrier, children under 36 months of age are particularly susceptible to neurologic damage at very low blood lead levels. Because children (to age 7) are more sensitive to lead's effects, most adverse effects of lead are often manifested at lower blood lead levels in children than in adults.

(10) Especially in young children, lead exposure can cause subtle but damaging developmental and neurologic effects that are very difficult to identify on physical examination. In the case study, for example, the boy appeared in good condition when he was brought in as a 2-year-old, but may have already been experiencing the onset of problems related to lead exposure, such as slightly impaired speaking ability, slightly duller mental capability. Because these effects can be so subtle, a physician cannot rely on physical examination alone to determine whether a child is at risk for elevated lead exposure. The physician must also ask questions about the child's environment.

(11) Taking a detailed family and environmental history and testing the patient's BLL are as important as a physical exam in determining whether or not a patient is at risk of adverse effects from lead exposure. A child's BLL or an environmental assessment can sometimes reveal that an asymptomatic child is at risk.

(12) History suggests delayed language ability, slightly impaired hearing, short stature, possible ADHD, anemia, and abdominal pain. The child is also experiencing passive exposure to his mother's cigarette smoke, family disruption, and possible stress related to his parents' divorce or to attending kindergarten.

(13) Three of the most common causes of microcytic anemia are iron deficiency, hemoglobinopathy, and lead poisoning. In lead-poisoned patients, anemia is usually evident only when the blood lead level is significantly elevated for prolonged periods. It manifests in only a relatively small number of children with chronic lead exposure. It is possible for a patient to be both lead-poisoned and to have anemia due to some other cause. The relative rarity of nutritional iron deficiency in this boy's age group and the absence of evidence for blood loss suggest consideration of other etiologies to explain the anemia.

(14) An elevated ZPP level is most often due to iron deficiency anemia, hemolytic anemias, or lead poisoning. A rare disease that may cause the ZPP level to be markedly elevated is erythropoietic protoporphyria.

(15) To confirm lead poisoning, the most sensitive test is a venous blood lead level. (This, or a screening capillary BLL, is usually the first test drawn, instead of the ZPP). If the blood lead level is below 25 µg/dL, a serum ferritin level and other iron studies can be used to determine if iron deficiency anemia exists.

(16) Knowing the subgroups at greatest risk of lead exposure, you should take every opportunity to educate these subpopulations, as well as your colleagues and the community, about the hazards of lead poisoning and the steps to prevent its occurrence. Those children and members of the community whom you suspect may be in danger of lead poisoning should be promptly screened.

(17) With an elevated blood lead level of 50 $\mu\text{g}/\text{dL}$, the conclusion is that the boy is lead-poisoned. In this case, the child should have a confirmation test and should be referred for appropriate chelation therapy immediately (within 48 hours). It is important to immediately identify and eliminate all sources of lead exposure for both the boy and his family. Environmental evaluation, intervention, and remediation should begin immediately. The health department should be contacted to begin this environmental evaluation and case management. All household members should be screened for lead exposure. You should emphasize the importance of adequate diet to the family, and they should begin lead education.

(18) You should consult with a physician experienced in treating lead-poisoned patients. To identify such physicians, contact your state or local health department, a university medical center, or a certified regional poison control center.

(19) In certain states, public health authorities must be notified if a patient's blood lead level and ZPP level exceed certain limits. In any case, you should contact your state or local health department so all sources of lead in the home can be identified and abated. You should also notify OSHA so the radiator repair shop can be brought, if required, into compliance with the federal lead standard. A NIOSH health hazard evaluation could also be requested. The reason for notifying these agencies is to prevent lead exposure in others.

(20) The federal lead standard mandates that a worker with a blood lead level of 60 $\mu\text{g}/\text{dL}$ or higher (or an average of 50 $\mu\text{g}/\text{dL}$) must undergo medical removal from the lead hazard and be reassigned with retention of job seniority and pay. In addition to referring her for obstetrical evaluation, you should recommend that the mother talk to her employer, employee representative, and OSHA to clarify her work status and possible reinstatement procedures under the lead standard.

Other Sources of Information

CDC Childhood Lead Poisoning Prevention Program

Web site: <http://www.cdc.gov/nceh/lead/lead.htm>

This program promotes state and local screening efforts and develops improved treatments for lead exposure.

National Lead Information Center Hotline and Clearinghouse

Telephone: 800-LEADFYI (Hotline)

Telephone: 800-424-LEAD (Clearinghouse)

Fax: 202-659-1192

E-mail: ehc@cais.com

Web site: <http://www.epa.gov/lead/nlicdocs.htm>

The Hotline is available 24 hours a day, 7 days a week, in English and Spanish. The Hotline distributes a basic information packet on lead that includes the EPA brochure *Lead Poisoning and Your Children*, three fact sheets, and a list of state and local contacts for additional information. Callers who have more specific questions are referred

to the Clearinghouse (800-424-LEAD) and can speak directly with an information specialist. Information specialists provide on-phone technical assistance.

Office of Pollution Prevention and Toxics

U.S. Environmental Protection Agency

Ariel Rios Building

1200 Pennsylvania Avenue, N.W.

Washington, DC 20460

Telephone: 202-260-2902

Lead Programs Web page: <http://www.epa.gov/lead>

Additional Sources

More information on the adverse effects of lead and the treatment and management of lead-exposed persons can be obtained from ATSDR, your state and local health departments, and university medical centers. ATSDR's toll-free line is: 1-888-42-ATSDR (1-888-422-8737).

Case Studies in Environmental Medicine:

Lead Toxicity

Evaluation Questionnaire and Posttest, Course Number SS3059

Course Goal: To increase the primary care provider's knowledge of hazardous substances in the environment and to aid in the evaluation of potentially exposed patients.

Objectives

- Discuss the major exposure route for lead.
- Describe two potential environmental and occupational sources of lead exposure.
- State two reasons why lead is a health hazard.
- Describe factors that contribute to lead toxicity.
- Identify evaluation and treatment protocols for persons exposed to lead.
- List two sources of information on lead.

Tell Us About Yourself

Please carefully read the questions. Provide answers on the answer sheet (page 55). Your credit will be awarded based on the type of credit you select.

1. What type of continuing education credit do you wish to receive?

****Nurses should request CNE, not CEU. See note on page 54.**

- A. CME (for physicians)
- B. CME (for non-attending)
- C. CNE (continuing nursing education)
- D. CEU (continuing education units)
- E. [Not used]
- F. [Not used]
- G. [Not used]
- H. None of the above

2. Are you a...

- A. Nurse
- B. Pharmacist
- C. Physician
- D. Veterinarian
- E. None of the above

3. What is your highest level of education?

- A. High school or equivalent
- B. Associate, 2-year degree
- C. Bachelors degree
- D. Masters degree
- E. Doctorate
- F. Other

- 4. Each year, approximately how many patients with lead exposure do you see?**
- A. None
 - B. 1–5
 - C. 6–10
 - D. 11–15
 - E. More than 15
- 5. Which of the following best describes your current occupation?**
- A. Environmental Health Professional
 - B. Epidemiologist
 - C. Health Educator
 - D. Laboratorian
 - E. Physician Assistant
 - F. Industrial Hygienist
 - G. Sanitarian
 - H. Toxicologist
 - I. Other patient care provider
 - J. Student
 - K. None of the above
- 6. Which of the following best describes your current work setting?**
- A. Academic (public and private)
 - B. Private health care organization
 - C. Public health organization
 - D. Environmental health organization
 - E. Non-profit organization
 - F. Other work setting
- 7. Which of the following best describes the organization in which you work?**
- A. Federal government
 - B. State government
 - C. County government
 - D. Local government
 - E. Non-governmental agency
 - F. Other type of organization

Tell Us About the Course

- 8. How did you obtain this course?**
- A. Downloaded or printed from Web site
 - B. Shared materials with colleague(s)
 - C. By mail from ATSDR
 - D. Not applicable

- 9. How did you first learn about this course?**
- A. State publication (or other state-sponsored communication)
 - B. *MMWR*
 - C. ATSDR Internet site or homepage
 - D. PHTN source (PHTN Web site, e-mail announcement)
 - E. Colleague
 - F. Other
- 10. What was the most important factor in your decision to obtain this course?**
- A. Content
 - B. Continuing education credit
 - C. Supervisor recommended
 - D. Previous participation in ATSDR training
 - E. Previous participation in CDC and PHTN training
 - F. Ability to take the course at my convenience
 - G. Other
- 11. How much time did you spend completing the course, and the evaluation and posttest?**
- A. 1 to 1.5 hours
 - B. More than 1.5 hours but less than 2 hours
 - C. 2 to 2.5 hours
 - D. More than 2.5 hours but less than 3 hours
 - E. 3 hours or more
- 12. Please rate your level of knowledge prior to completing this course.**
- A. Great deal of knowledge about the content
 - B. Fair amount of knowledge about the content
 - C. Limited knowledge about the content
 - D. No prior knowledge about the content
 - E. No opinion
- 13. Please estimate your knowledge gain due to completing this course.**
- A. Gained a great deal of knowledge about the content
 - B. Gained a fair amount of knowledge about the content
 - C. Gained a limited amount of knowledge about the content
 - D. Did not gain any knowledge about the content
 - E. No opinion

Please use the scale below to rate your level of agreement with the following statements (questions 14–25) about this course.

- A. Agree
- B. No opinion
- C. Disagree
- D. Not applicable

- 14. The objectives are relevant to the goal.**
- 15. The tables and figures are an effective learning resource.**
- 16. The content in this course was appropriate for my training needs.**
- 17. Participation in this course enhanced my professional effectiveness.**
- 18. I will recommend this course to my colleagues.**
- 19. Overall, this course enhanced my ability to understand the content.**
- 20. I am confident I can discuss the major exposure route for lead.**
- 21. I am confident I can describe two potential environmental and occupational sources of lead exposure.**
- 22. I am confident I can state two reasons why lead is a health hazard.**
- 23. I am confident I can describe factors that contribute to lead toxicity.**
- 24. I am confident I can identify evaluation and treatment protocols for persons exposed to lead.**
- 25. I am confident I can list two sources of information on lead.**

Posttest

If you wish to receive continuing education credit for this program, you must complete this posttest. Each question below contains four suggested answers, of which one or more is correct. Choose all correct answers for each question:

26. Early indications of lead poisoning in children may be:

- (A) inappropriate classroom behavior
- (B) impaired speech or hearing
- (C) fatigue and lethargy
- (D) anemia and dermal rash

27. A laboratory evaluation for lead toxicity might include:

- (A) CBC with peripheral smear
- (B) blood lead level
- (C) zinc protoporphyrin level
- (D) cardiac enzymes and liver function tests

28. Potential sources of dietary lead include

- (A) solder used to seal food and drink containers
- (B) imported pottery
- (C) household dirt and dust
- (D) folk remedies

29. Which of the following concerning lead in the body is false?

- (A) always a potential health risk
- (B) sometimes mobilized in times of stress or malnutrition
- (C) associated with erythrocytes in the blood and bioaccumulated in the bones and teeth
- (D) of no consequence below a level of 10 $\mu\text{g}/\text{dL}$

30. Children are generally at greater risk than adults from the effects of lead because:

- (A) children consume more sweets
- (B) children show a greater prevalence of iron deficiency
- (C) children commonly drink more milk
- (D) children ingest more dirt and children show a greater sensitivity to lead's effects

31. Erythrocyte protoporphyrin (EP) or zinc protoporphyrin (ZPP) values may be elevated:

- (A) when blood lead levels are chronically elevated
- (B) in hyperbilirubinemia
- (C) in erythropoietic protoporphyria
- (D) in iron-deficiency anemia

32. The following information obtained during a medical evaluation may provide clues to a potential lead exposure:

- (A) occupational history of all home occupants and health of household pets
- (B) location, age, and physical condition of residence
- (C) family activities such as home remodeling
- (D) source of drinking water

33. The following are symptoms of mild (rather than severe) lead toxicity:

- (A) wrist drop
- (B) myalgia
- (C) blue-black line on gingival tissue and anemia
- (D) hyperactivity

Note to Nurses

CDC is accredited by the American Nurses Credentialing Center's (ANCC) Commission on Accreditation. ANCC credit is accepted by most State Boards of Nursing.

California nurses should write in "ANCC - Self-Study" for this course when applying for relicensure. A provider number is **not** needed.

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Case Studies in Environmental Medicine:

Lead Toxicity

Answer Sheet, Course Number SS3059

Instructions for submitting hard-copy answer sheet: Circle your answers. To receive your certificate, you must answer **all** questions. Mail or fax your completed answer sheet to

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