Lead Poisoning: A Heavy (Metal) Topic of Discussion

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Objectives

1. Describe the pathophysiology of lead poisoning.
2. Discuss clinical manifestations of lead toxicity.
3. Explain the role of the clinical laboratory in detection and monitoring of lead exposure.

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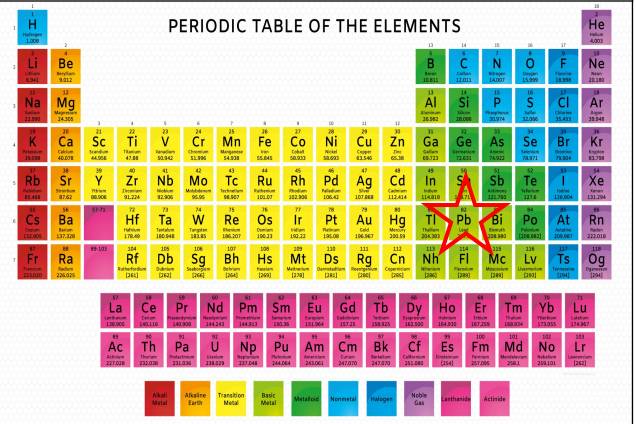
What is lead?

- Pb, from Latin word *plumbum*
- Atomic number 82
- Soft, malleable bluish-white metal
- Heavy metal: large atomic mass with densely packed atoms



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Lead, cont.

- Occurs naturally in small amounts in the earth's crust
- Found in concentrated ore deposits widely distributed throughout the world: US, Canada, Spain, Germany, South America, Africa, and Australia
- Harmful or toxic if inhaled or swallowed and can pose serious health risks
  - Young children
  - Pregnant females

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Historical context

- Mentioned often in early biblical accounts
- Used by Babylonians as plates on which to record inscriptions
- Romans: tablets, water pipes, coins, wine vessels, cooking pots and utensils
- Long associated with toxicity and illness
- Benjamin Franklin described lead poisoning in early printers (1763)

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Modern era (in the U.S.)

- Became a major health concern in the 20th century
  - Leaded gasoline phased out starting in 1973; officially banned in 1996
  - Lead paint banned for residential use in 1978
  - Lead in plumbing banned in 1986
- Remains a significant public health issue despite regulations

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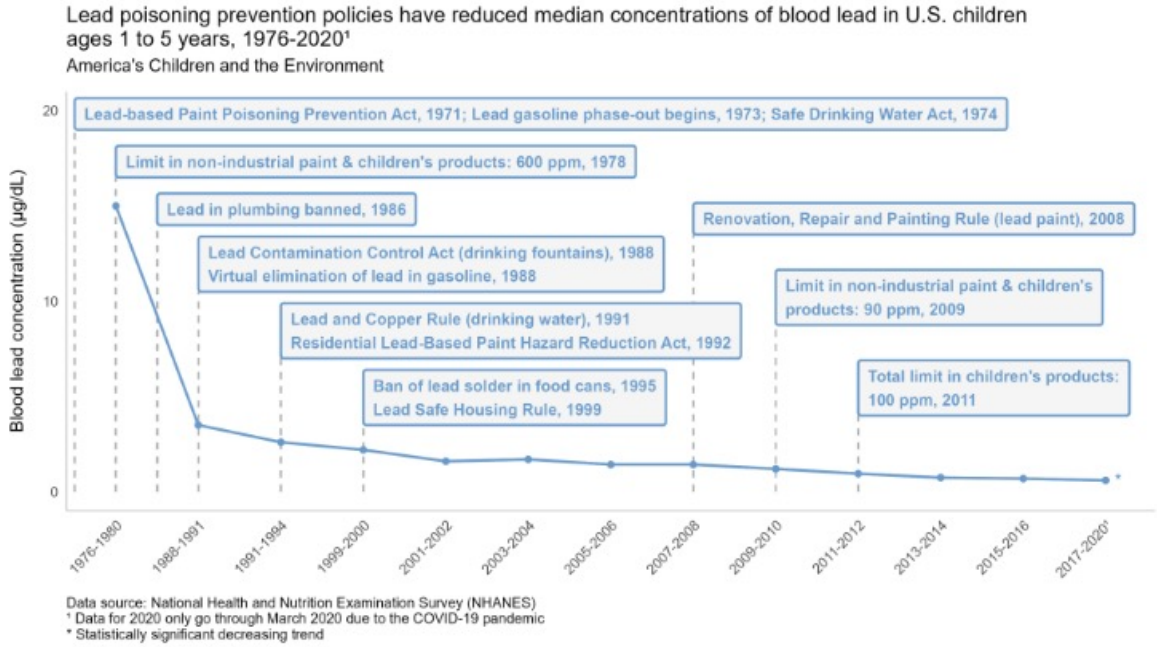

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Sources of Lead Exposure

- **Environmental**: lead-based paint, contaminated soil ("legacy contamination"), drinking water
- **Consumer products**
  - Imported: toys, costume jewelry, cosmetics, vinyl lunchboxes & backpacks, foods, spices, or candy
  - Ammunition and fishing tackle: lead bullets and shot, lead sinkers
  - Hobby materials: stained glass work, pottery glazes, oil painting

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Sources, cont.

- **Occupational**: battery manufacturing & recycling, construction & renovation, auto repair, firing ranges, mining, ship building & bridge construction, stained glass and pottery work
  - Take-home contamination
- **Industrial contamination**: lead refineries, battery recycling facilities, mining operations; air/water/soil contamination from industrial sites

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Benefits of lead

- Paint: superior coverage, faster drying, durability, weather resistance, rust inhibition
- Gasoline: more powerful and efficient engines
- Batteries: efficiently stores and releases electricity
- Radiation shielding: blocks X-rays and gamma rays
- Construction and plumbing: durable and resists corrosion
- Ammunition: increased mass in small volume, improved accuracy
- Glass: increased weight, sparkle, and ease of cutting

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Vulnerable Populations

- Children under 6 y/o
- Pregnant individuals
- Low-income populations
- Residents in older housing
- Those consuming imported foods/spices
- Certain occupations

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Clinical Symptoms of Lead Toxicity

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Acute Exposure (rare)

- Occurs with very high exposure (BLL >70 µg/dL)
  - Severe abdominal pain (“lead colic”)
  - Vomiting
  - Constipation
  - Seizures
  - Encephalopathy
  - Coma
  - Death (if untreated)

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Acute Exposure, cont.

- Most commonly from:
  - Industrial accidents
  - Ingestion of large amounts of lead-containing materials
  - Criminal poisoning (rare)

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Chronic Exposure (more common)

- Symptoms develop gradually due to continued exposure
- Often non-specific
- May be initially attributed to other causes
- Children particularly vulnerable

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Physiologic Effects

- Neurologic
- Hematologic
- Renal
- Gastrointestinal
- Cardiovascular
- Reproductive

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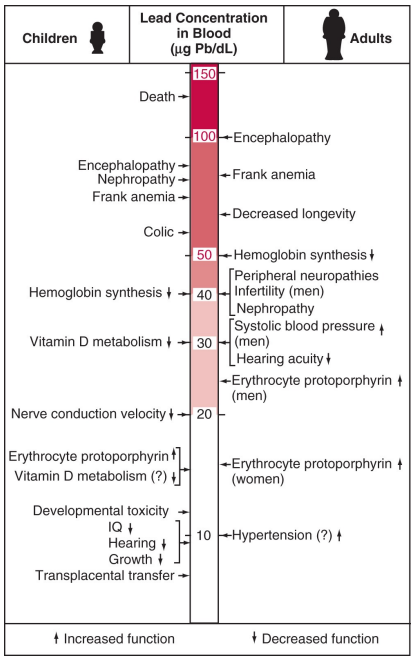

Effects of Lead on Children and Adults

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Pathophysiology of Lead Toxicity

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Routes of Lead Absorption

- Gastrointestinal (GI)
  - Children: ~50% absorption
  - Adults: 10-15% absorption
  - Enhanced by empty stomach, iron and/or calcium deficiency
- Respiratory (most efficient): nearly 100% of inhaled lead particles <2.5 μm
- Dermal: minimal

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Lead Distribution in the Body

- **Blood** (half-life ~30 days)
  - ~99% bound to RBCs via hemoglobin
  - <1% in plasma
  - Blood lead level (BLL) reflects recent exposure
- **Soft tissues** (half-life ~40 days)
  - Liver, kidneys, brain, muscles
  - Sites of toxic effects
- **Bone** (half-life 20-30 years)
  - ~95% of total body burden in adults
  - ~70% in children
  - Mobilized during:
    - Pregnancy
    - Lactation
    - Menopause
    - Hyperthyroidism
    - Osteoporosis

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Excretion of Lead

- Renal: ~75%
- Fecal: ~15%
- Minor routes: hair, nails, sweat, breast milk
- Occurs slowly, so bioaccumulation is a concern

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Mechanisms of Lead Toxicity

- **Direct DNA damage**
  - Interference with DNA repair mechanisms
  - Potential carcinogenic effects
- **Calcium interference**
  - Mimics calcium
  - Disrupts release of neurotransmitters
  - Responsible for neurotoxic effects
- **Oxidative stress**
  - Depletes natural antioxidants
  - Damages cell membranes
  - Contributes to shortened RBC survival

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Mechanisms of Lead Toxicity, cont.

- **Inhibition of RNA degradation in maturing RBCs**
  - RNA aggregates accumulate within the cell
  - Coarse, dark blue granules visible on Wright stain
  - May shorten RBC lifespan

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Mechanisms of Lead Toxicity, cont.

- **Disruption of heme synthesis**
  - Inhibits two key enzymes
    - **δ-Aminolevulinic acid (ALA) dehydratase** – most sensitive to lead; results in δ-ALA accumulation in blood & urine
    - **Ferrochelatase** – most clinically significant; results in excess incomplete heme rings in blood and iron accumulation in bone marrow

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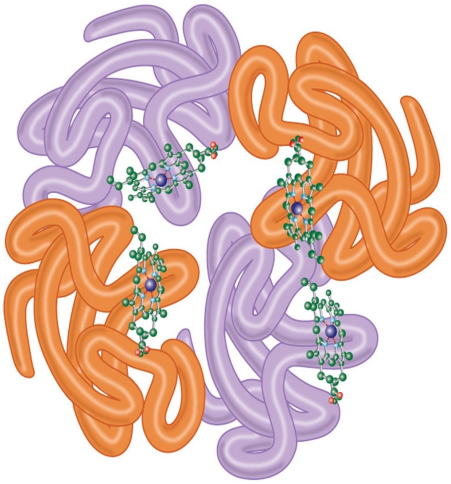
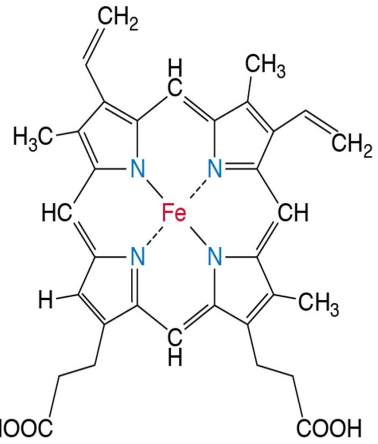


Hemoglobin



Heme structure

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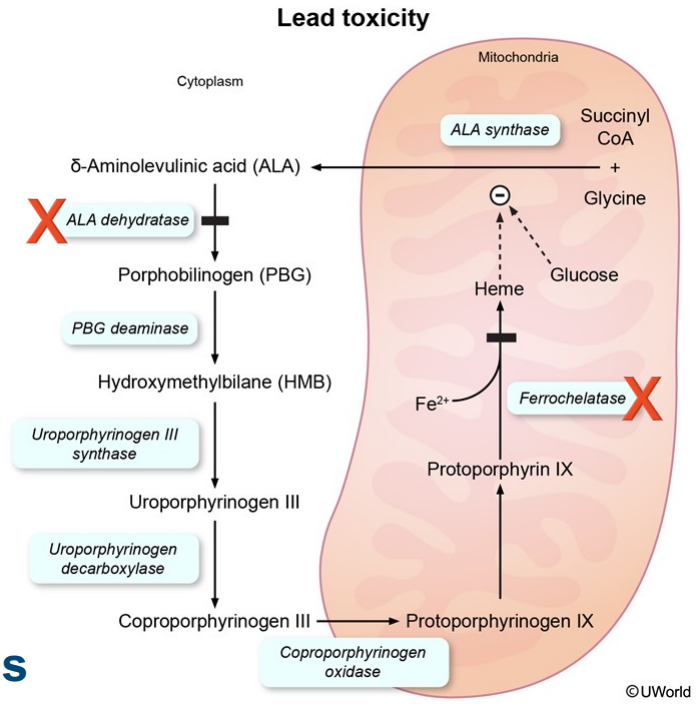
Heme Biosynthesis



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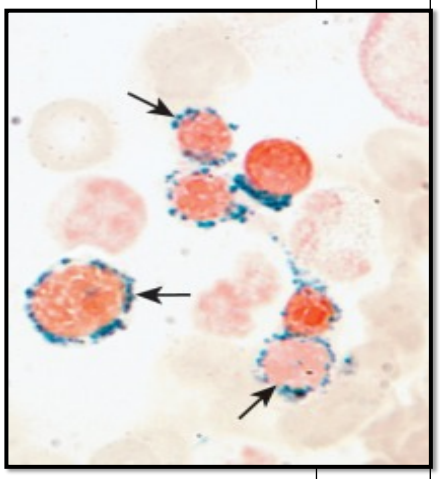
Hematologic Consequences of Lead Toxicity

- **Sideroblastic anemia**
  - Ringed sideroblasts in bone marrow
    - Iron encircles developing RBC nuclei in mitochondria
    - Mitochondria rupture, causing iron overload
  - Basophilic stippling in peripheral blood
    - Punctate RNA aggregates in mature RBCs
  - Decreased RBC survival leads to anemia
    - Ineffective marrow production of RBCs
    - Defective RBCs have shortened lifespan



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Laboratory Testing and Findings

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Pre-analytical Considerations

- **Contamination prevention is critical**
  - Standard evacuated tubes may contain lead
  - Clean skin thoroughly and use proper venipuncture technique
  - Avoid hemolysis (most circulating lead is intracellular)
  - Capillary samples acceptable for screening only
- Specimens are stable for 30 days if refrigerated

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Blood Lead Level (BLL)

- Gold standard
- Specimen: Whole blood, K_2EDTA – preferably royal blue top (trace element) tube
- Analysis methods: mass spectrometry – highly sensitive and specific; voltammetry – POC devices for screening

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Reference Values

- **No safe blood lead level (BLL) established by CDC**
- CDC currently uses **3.5 µg/dL** as the reference value
- Any detectable BLL means the person has been exposed to lead.
  - Typical BLL in U.S. adults is ~0.85µg/dL or less
- Most experts recommend intervention at levels ≥10 µg/dL
- Pregnant women: begin interventions at ≥5 µg/dL

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Blood Lead Level (µg/dL)	Interpretation	Recommended Actions
< 3.5	Within expected range	- Routine screening based on age/risk - Provide education on lead exposure prevention
3.5 – 9	Elevated (above reference value)	- Confirm with repeat test (venous sample) - Educate caregivers on sources of lead - Nutritional counseling (iron, calcium) - Environmental exposure history
10 – 19	Moderately elevated	- Report to local health department - Environmental investigation of home - Monitor development and nutrition
20 – 44	High	- Full medical evaluation - Detailed environmental investigation - Consider abdominal X-ray (if ingestion suspected) - Consult specialists (e.g., toxicology) - Follow-up testing frequently
45 – 69	Very high	- Urgent medical evaluation - Initiate chelation therapy - Hospitalization may be required - Immediate environmental intervention
≥ 70	Severe, medical emergency	- Emergency hospitalization - Immediate chelation therapy - Intensive monitoring (neurologic risk) - Rapid environmental control

www.cdc.gov/lead-prevention

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Zinc Protoporphyrin (ZPP)

- AKA Free Erythrocyte Protoporphyrin (FEP)
- When lead inhibits ferrochelatase, zinc substitutes for iron in protoporphyrin ring
- Is easily detected by fluorescence
- ZPP/FEP elevation reflects chronic lead exposure (over ~120 days)

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ZPP, cont.

- Normal: <35 µg/dL
- Elevated: indicates chronic lead exposure OR iron deficiency
- Limitations: Not specific for lead, not sensitive at levels <25 µg/dL
- Utility as a screening tool for adults and to monitor chronic exposure – remains elevated longer than BLL once exposure stops

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Hematology Lab Findings

Complete Blood Count (CBC)

- Mildly decreased Hgb
- Decreased MCV, MCH, MCHC
- Increased RDW
- Increased reticulocyte count

Peripheral Blood Smear

- Microcytic, hypochromic cells
- Polychromasia
- RBC size variation (anisocytosis)
- Basophilic stippling

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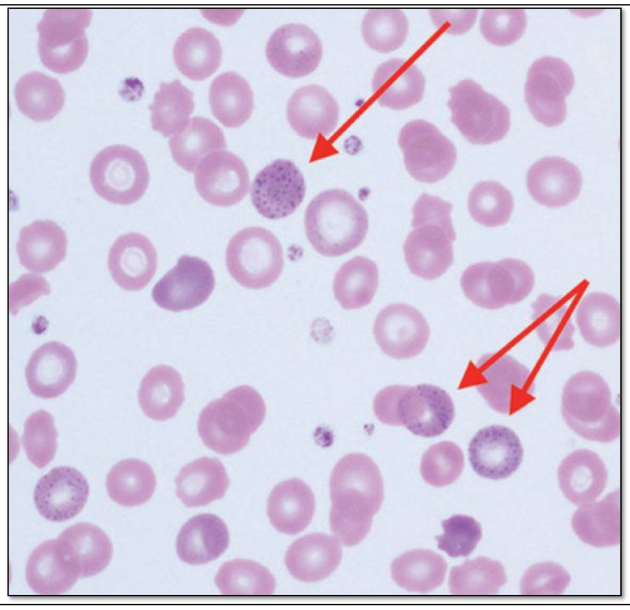
Basophilic Stippling in Mature RBCs



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Iron Studies

Test	Lead Poisoning	Iron Deficiency Anemia (IDA)
Serum Iron	↑ Increased	↓ Decreased
Serum Ferritin	**↑ Increased**	**↓ Decreased**
%Transferrin Saturation	↑ Increased	↓ Decreased
Total Iron Binding Capacity	Normal or ↓ decreased	↑ Increased
ZPP/FEP	↑↑ Markedly increased	↑ Increased
Bone Marrow Iron Stores	Normal or ↑; ringed sideroblasts	↓ Absent

Key Distinction: Lead poisoning causes a functional iron deficiency, while iron deficiency anemia is caused by true iron depletion.

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Other Significant Findings

Chemistry

- Elevated uric acid
- Elevated creatinine
- Elevated BUN

Imaging/Visual

- X-ray
  - "Lead lines" on the ends of bones in children
  - Possible lead particles seen in abdomen if recently ingested
- Dental
  - Burton's line
  - Severe enamel defects

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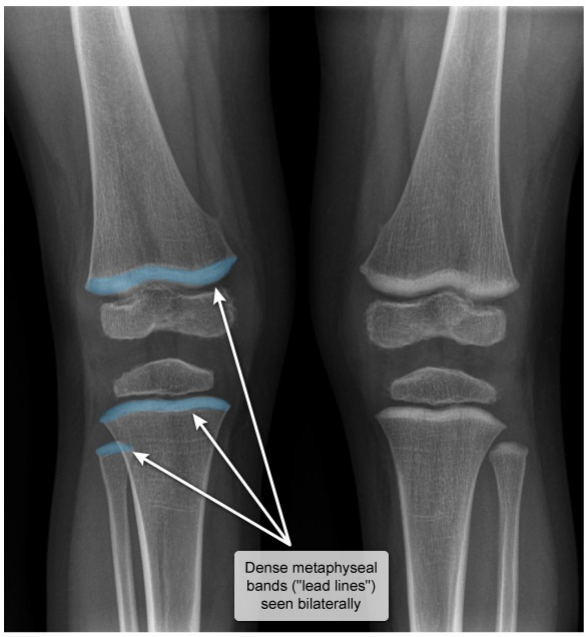
Knee radiograph in a patient with chronic lead exposure



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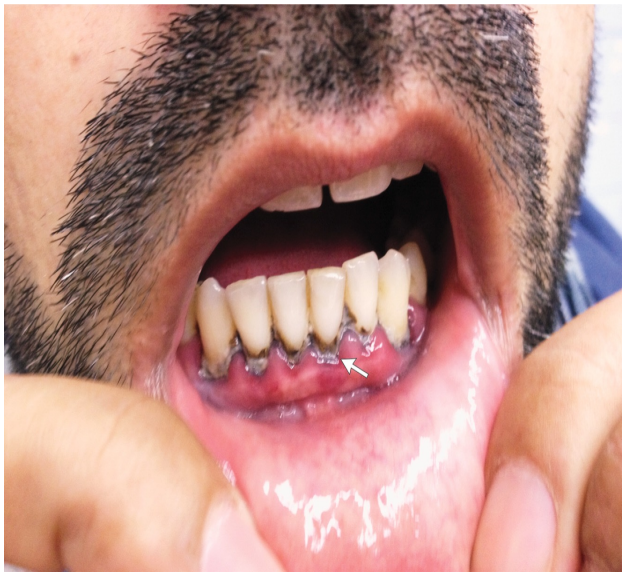

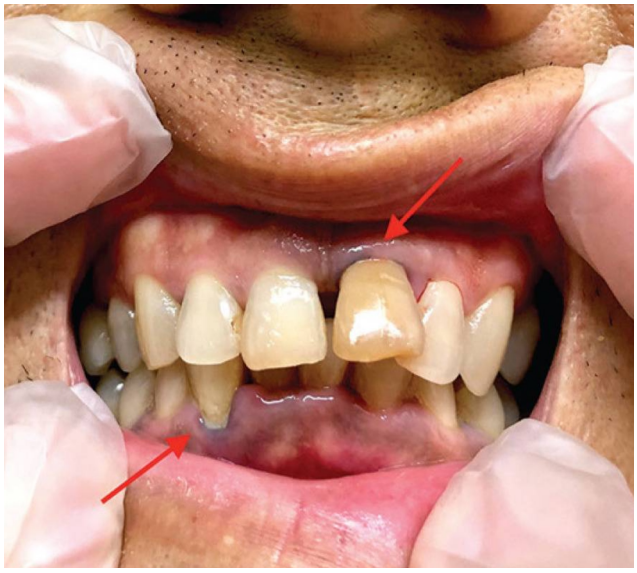

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Management and Treatment

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Remove Source (most important)

- For children
  - Home inspection by certified lead inspector
  - Cleaning, repairs, removal of lead hazards
  - Relocation if necessary
- For workers
  - Engineering controls, PPE
  - Hygiene practices
  - Medical removal from job if necessary

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Nutritional Interventions

- Iron supplementation – deficiency increases lead absorption
- Calcium supplementation – lead competes with calcium for absorption
- Vitamin C – may enhance lead excretion
- Regular meals – fasting increases lead absorption
- Balanced diet – adequate protein, limited fat

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Chelation Therapy

- Binds lead in blood or soft tissues, forms compounds that can be safely excreted in urine or feces
- May require multiple courses if BLL remains elevated
- Rebound phenomenon: BLL may increase after chelation as lead redistributes from bone
- In children: BLL ≥45 µg/dL OR if symptomatic, or BLL continue to rise despite intervention
- In adults: BLL ≥80-100 µg/dL OR if symptomatic regardless of BLL

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Chelation Controversy

- Benefit of chelation at lower BLL (20-44 µg/dL) unclear
- Studies in lead-exposed children lowered BLL but did not improve cognitive impairments
- Current practice is to reserve chelation for higher BLL or symptomatic cases

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Regulatory Oversight

- Centers for Disease Control and Prevention (CDC)
- Environmental Protection Agency (EPA)
- Occupational Safety and Health Administration (OSHA)
- Food and Drug Administration (FDA)
- Consumer Product Safety Commission (CPSC)
- Department of Housing and Urban Development (HUD)
- Louisiana Department of Health (LDH)

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Key Takeaways

- Lead poisoning remains a significant public health problem despite declining prevalence.
- No safe blood lead level has been identified.
- Blood lead level (BLL) is the gold standard test; use trace element tubes to avoid contamination.
- Heme synthesis disruption is the key pathophysiological mechanism affecting laboratory findings.
  - Zinc protoporphyrin (ZPP) reflects chronic exposure but is not specific for lead.
  - Differentiate lead toxicity from iron deficiency using iron studies.
- Children are most vulnerable to neurotoxic effects.
- Environmental remediation is the cornerstone of treatment.
- Chelation therapy is reserved for higher BLL or symptomatic patients.
- Laboratory professionals play a vital role in screening, diagnosis, and public health surveillance.

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Thanks for listening! Any questions?

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