

Effects of Chronic Lead Exposure on Hematological Indices in Albino Rats (*Rattus norvegicus*)

Authors:

Ofoegbu EC^{1*} and Onyeka PIK²

¹Prime British International College Owerri.

²Anatomy and Physiology Unit, Department of Animal and Environmental Biology Imo State University Owerri.

<https://orcid.org/0009-0000-5590-497X>

Corresponding Author:

Ofoegbu EC, Prime British International College Owerri.

DOI: <https://doi.org/10.5281/zenodo.20251920>

Received: 04-April-2026, Accepted: 20-April-2026, Online First: 25-April-2026

ABSTRACT:

This study was carried out to determine the effect of Lead Toxicity on the Physiology (Hematological indices) of Albino Rats (*Rattus norvegicus*). Lead exposure remains a major environmental and public health concern due to its toxic effects on hematological and physiological functions. A total of forty-eight (48) Albino Rats were procured and divided into two experimental groups of twenty-four (24) Albino Rats per group. One group of rats was treated with lead in their drinking water while the other was treated with lead in their feed. Also, a common control group which was made of twelve rats. Each experimental group was made up of three treatments sub-group which consisted of different concentration levels of 50 mg/kg, 100 mg/kg and 150 mg/kg. A one-way ANOVA was conducted to examine the effect of lead toxicity on the hematological indices of albino rats. The results revealed that lead exposure produced statistically significant effects on all parameters measured Hemoglobin ($F(2,4) = 49.14, p = 0.002$), PCV ($F(2,4) = 13.44, p = 0.017$), WBC ($F(2,4) = 29.62, p = 0.004$), and RBC ($F(2,4) = 21.06, p = 0.008$). Post hoc analysis using the Tukey HSD test showed that for each of these indices, the Control group differed significantly from both the Low and High lead exposure groups ($p < 0.05$), indicating that lead toxicity markedly altered the hematological parameters. In particular, hemoglobin concentration, PCV, and RBC counts decreased with increasing lead exposure, while alterations in WBC counts suggested immune response activation associated with lead toxicity. However, the study was limited by the relatively small sample size and lack of biochemical oxidative stress marker assessment. The results underscore the need for regular monitoring of Hematological parameters in individuals exposed to lead.

Keywords: Lead toxicity, Hematological indices, Albino rats, Oxidative stress, Chronic exposure, Heavy metals

INTRODUCTION:

All living things, from one-celled microorganisms to blue whales, depend on earth's supply of air and water to survive. When these resources are polluted, all forms of life are threatened. Pollution is the introduction or release of harmful materials into the environment. Environmental pollution involves the presence of a pollutant in the environment such as water, air, soil and consequently in food which may be poisonous or toxic and will cause harm to living things in the polluted environment (Oguntimehin, *et al.*, 2022). Many useful things to humans produce pollution. These are referred to as pollutants. Cars spew pollutants from their exhaust pipes. Burning coal to create electricity pollutes the air. Industries and households generate garbage and sewage that can pollute the land and water. Pesticides-chemical poisons used to kill weeds and insects-seeps into water

ways and harm wildlife. All these and many more are examples of pollutants. The excessive amount of pollutants such as heavy metals in animal feed and feed stuff is often due to human action and their results from either agricultural or industrial production or through accidental or deliberate misuse (Adetunji, *et al.*, 2020). Heavy metals are generally defined as metals with relatively high densities, atomic weights or atomic numbers (Pourret, *et al.*, 2021). Lead (Plumbum; Pb) is a toxic heavy metal and a chemical element belonging to the carbon group. It is soft, malleable, and widely distributed in the environment due to industrial and agricultural activities. Lead introduced into the blood stream is excreted in urine and bile at a distinct rate of 1 to 3ml/min, with a half-life of roughly 30 days. The remaining leads bind to red blood cells and are distributed throughout the soft tissues of the body and

eventually accumulate in bone. The half-life of bone-deposited lead ranges from 20 to 30 years. Turnover of bone tissue releases lead back into the bloodstream and Physiological processes such as pregnancy, menopause, and lactation may increase blood lead levels by enhancing bone tissue turnover. Lead in the body is measured with both blood and bone levels. Blood lead levels are more reflective of acute exposure, whereas bone lead levels better reflect cumulative exposure over time (ATSDR, 2020). Lead is known to induce overproduction of reactive oxygen species (ROS) and consequently enhance lipid peroxidation, decrease the saturated fatty acids, and increase the unsaturated fatty acid contents of membrane (Hassan *et al.*, 2020). Lead has also been shown to enhance the production of reactive oxygen species in a variety of cells, resulting in oxidative stress (Li *et al.*, 2022).

Although several studies have investigated lead toxicity, limited information exists regarding comparative hematological effects associated with different routes of chronic lead exposure, particularly through feed and aqueous administration. Therefore, this study aimed to evaluate the effects of chronic lead exposure on selected hematological indices in albino rats using two different exposure models.

Despite a number of recent studies (Lakshmi *et al.*, 2020; Nriagu, 2011; Adewuyi, and Adewuyi, 2018; WHO, 2017), many aspects of normal lead metabolism are poorly understood hence the research work will help in formulating appropriate public policies and regulation to protect individuals and communities. It will provide scientific evidence to support initiatives such as banning or restricting the use of lead in consumer products, implementing lead testing and remediation programs, and setting standards for safe lead levels in different environments. The research findings can guide public health interventions and strategies to prevent and mitigate lead exposure; this include targeted screening programs to identify individuals at risk, educational programs to create awareness and sensitize the populace on the effect of lead toxicity on human health and interventions to address lead-contaminated environments. It can also help to inform healthcare professionals about the best practices for lead poisoning prevention, diagnosis and treatment. The research work will also help to identify vulnerable population that are most affected by lead toxicity, this information is crucial for targeting intervention and resources to protect those at higher risk, such as children, pregnant women, individuals living in high risk environment, and certain occupational groups. By understanding the specific factors that contribute to lead exposure disparities, researchers can help address social and environmental justice issue related to lead toxicity.

MATERIALS AND METHODS:

Study Area:

Imo State is among the 36 states of Nigeria and lies in the South eastern region of the country. It lies within Latitude: 5.4833° N, Longitude: 7.0333° E, with area of about 5100sqk and a population of about 3,934899 (NBS 2022; NPC 2006). The research study was carried out at the Animal house of the Department of Anatomy and Neurobiology, Imo State University Owerri and Sabconsults Research Laboratories Ltd Owerri

Ethical Consideration:

The study protocol was reviewed and approved by the Research Ethics Committee of the Department of Animal and Environmental Biology, Imo State University, Owerri. All experimental procedures were conducted in accordance with the National Research Council (NRC) Guide for the Care and Use of Laboratory Animals (2011) and complied with ARRIVE guidelines for animal research reporting. Efforts were made to minimize animal suffering and reduce the number of animals used.

Experimental Sites:

The experiment was carried out in the Animal house of the Department of Anatomy and Neurobiology, Faculty of Medical Science, Imo State University, Owerri and Sabconsults Research Laboratories Ltd Owerri.

Procurement and Management of Experimental Animals:

48 rats within the age bracket of six (6) to ten (10) weeks old were purchased from the suppliers and transported to the Animal house of the Department of Anatomy and Neurobiology, Imo State University Owerri. The rats were allowed to acclimatize in the experimental animal house for two weeks before the commencement of the experiment. Animals were randomly assigned to the experimental groups to minimize selection bias.

They were kept in stainless wire-rat cages equipped with drinkers and fecal collecting trays in a clean experimental animal house. The rats were fed with broiler chicks mash. The faecal droppings were removed daily. The rats were weighed with Mettler, electronic balance PC 2000 during treatment. All the rats in both treatment and control groups were allowed free access to food and water, throughout the experimental period. Good hygiene was maintained by constant cleaning and removal of feces and spilled feed from cages daily. They were separated into seven experimental groups, including one control group and six treatment groups.

Procurement, Preparation and Preservation of Chemicals:

Lead was purchased from a chemical store at Relief Market in Owerri Municipal. The desired doses 50 mg/kg, 100 mg/kg and 150 mg/kg (0.05%, 0.1% and 0.15%) that were used in this study was prepared with distilled water. For treatment Group A while the same measurement was mixed in the feed for treatment Group

B. The remaining lead were stored in a cool dry place. Lead chemicals can be prepared and preserved through various methods, including the use lead oxide and lead acetate (Osha, 2020)

Experimental Design:

A total of 48 albino rats were used for this research work. The experiment consisted of two major exposure groups: lead administered through aqueous solution and lead mixed in feed. Each exposure group was further divided into three treatment subgroups (A, B, and C) consisting of 6 rats per subgroup and exposed to 50 mg/kg, 100 mg/kg, and 150 mg/kg of lead respectively. A separate control group received normal feed and water under the same environmental conditions.

Dose selection was based on previous toxicological studies demonstrating sub-lethal chronic lead exposure effects in rodents. The sample size was determined based on feasibility and previous similar experimental studies. Both aqueous and feed-based exposure models were selected to simulate different environmental exposure routes.

Animals were randomly assigned to the different experimental groups. The portal of administration followed the oral exposure method described by Ekeh et al. (2015). The experiment lasted for 8 weeks, during which hematological parameters were monitored periodically.

Group	Exposure	Dose	n
Control	Normal feed/water	0	12
A1	Aqueous lead	50 mg/kg	6
A2	Aqueous lead	100 mg/kg	6
A3	Aqueous lead	150 mg/kg	6
B1	Feed mixed	50 mg/kg	6
B2	Feed mixed	100 mg/kg	6
B3	Feed mixed	150 mg/kg	6

Collection of Blood Sample and Preparation of Serum Samples for Analysis:

The method adopted for the collection of blood and serum preparation followed that of Hoff (2000). Blood samples was collected from the animal with a Pasteur pipette with the aid of capillary inserted at the corner of the eye ball. The blood collected from the animals in the different groups were introduced into clean 5 ml centrifuge tubes. The blood samples were centrifuged at a speed of 3000 revolutions per minute (rpm) for 5 minutes (Ogbu and Okechukwu, 2001). The supernatants (sera) were collected and used for the various biochemical and hematological analyses.

Hematological Indices:

The complete blood count was assessed using a multi-parameter automated haematology analyzer Sysmex

KX-21 (Sysmex Corporation Kobe, Japan). The principle is adapted to the volumetric impedance method (Robinson and Wallace, 2013); in which total white blood cells (WBC), red blood cells (RBC), are directly measured using the DC detection method; while a non-cyanide hemoglobin analysis method determines haemoglobin (HGB). Other variables such as hematocrit (HCT), is derived variable.

Statistical Analysis:

Data were analyzed using Statistical Package for Social Sciences (SPSS) version 20. Results are presented as mean $\pm$ standard deviation (SD). Normality of data distribution was assessed using the Shapiro–Wilk test prior to parametric analysis. Differences among groups were analyzed using one-way Analysis of Variance (ANOVA) followed by Tukey’s post hoc multiple comparison test. A p-value of ≤ 0.05 was considered statistically significant.

RESULT:

Table 1 showed a summary of the Hematological Indices for the Albino rats across the entire study period. Lead exposure, regardless of dose or method, resulted in a significant decline in Hemoglobin (HEMO), Packed Cell Volume (PCV), White Blood Cells (WBC), and Red Blood Cells (RBC). For Red Blood Cells (RBC), the Aqueous 50 mg/kg group remained the closest to the control for Red Blood Cell (RBC) count, the Aqueous 50 mg/kg group remained closest to the control group., Also for White Blood Cells (WBC), the Mixed in Feed groups (all doses) maintained slightly higher WBC levels (WBC $\rightarrow \times 10^9/L$) than the Aqueous groups (60.62–66.19 mg/dL). The Packed Cell Volume (PCV) levels for all treated groups dropped by approximately 13% to 16% compared to the control. Table 2 showed that every single lead-treated group recorded levels significantly below the baseline of the control (12.50 and 12.60 g/dl). The 100 mg/kg (aqueous group) dose dropped sharply to 9.70 g/dl at Week 4 and By Week 8, the 50 mg/kg dose was at its lowest point (10.10 g/dl). The lowest dose in feed showed a very steady, progressive decrease from 11.12 g/dl (Week 2) down to 10.35 g/dl (Week 8). The 100 mg/kg dose showed a curious spike to 11.70 g/dl at Week 6 before falling back to 10.24 g/dl at Week 8. Table 3 revealed that the most severe drops were generally associated with the higher concentrations (100 and 150 mg/kg), of aqueous solution groups. The 100 mg/kg (aqueous solution) group showed a sharp decline, starting at 40.60% in Week 2 and falling to 35.10% by Week 4. The 150 mg/kg group started low (38.80%) and dropped further by Week 4 (36.20%). The 100 mg/kg dose in feed started at 32.40% at Week 2, but then 38–40% for the remainder of the study. The 150 mg/kg dose showed a steady downward trend from Week 2 (40.05%) to Week 8 (38.06%). Table 4 showed that every lead-treated group remained below the

control baseline (20.12 to 20.50 cells/ μ l) throughout the 8-week study. Lead mixed in feed generally maintained slightly higher WBC counts than lead in aqueous solution, though both were still lower than the healthy control. The 100 mg/kg dose (aqueous group) at Week 6 reached the lowest point at 13.40 cells/ μ l (a ~35% decrease from control). The 50 mg/kg dose in feed remained relatively stable but consistently suppressed, hovering between 17.13 and 18.65 cells/ μ l. Table 5 presents that every lead-treated group, regardless of dose or delivery method, showed a marked decrease,

with counts mostly staying within the 6.00 to 7.00 range when compared to the control. In Aqueous Solution, the 100 mg/kg dose showed a steady reduction, ending at 6.20 by Week 8 and also both the 100 and 150 mg/kg doses dropped significantly by Week 2. The group (mixed in feed) recorded the lowest RBC counts, the 50 mg/kg dose dropped to 5.90 at Week 4, and the 100 mg/kg dose stayed consistently low (6.08–6.25) from Week 4 onward.

Table 1: Effect of Chronic Lead Exposure on Hematological Indices of Albino Rats

Treatment Group	Hb (g/dL)	PCV (%)	WBC ($\times 10^9/L$)	RBC ($\times 10^{12}/L$)
Aqueous Lead 50 mg/kg	11.8 $\pm$ 0.5	40.2 $\pm$ 1.3	16.2 $\pm$ 1.1	7.30 $\pm$ 0.24
Aqueous Lead 100 mg/kg	10.9 $\pm$ 0.4	37.1 $\pm$ 1.5	14.8 $\pm$ 1.0	6.62 $\pm$ 0.28
Aqueous Lead 150 mg/kg	10.5 $\pm$ 0.6	36.4 $\pm$ 1.7	14.2 $\pm$ 1.2	6.45 $\pm$ 0.31
Feed-Mixed Lead 50 mg/kg	11.4 $\pm$ 0.5	39.0 $\pm$ 1.4	17.4 $\pm$ 1.0	6.89 $\pm$ 0.26
Feed-Mixed Lead 100 mg/kg	10.8 $\pm$ 0.4	37.8 $\pm$ 1.5	16.7 $\pm$ 1.1	6.40 $\pm$ 0.29
Feed-Mixed Lead 150 mg/kg	10.6 $\pm$ 0.5	37.2 $\pm$ 1.6	16.1 $\pm$ 1.0	6.33 $\pm$ 0.30
Control	12.6 $\pm$ 0.3	44.5 $\pm$ 1.2	20.3 $\pm$ 0.9	8.01 $\pm$ 0.22

Values are expressed as mean $\pm$ standard deviation (SD). Hb: Hemoglobin; PCV: Packed Cell Volume; WBC: White Blood Cell Count; RBC: Red Blood Cell Count. *p < 0.05 compared with control group.

Key:

HEMO: Haemoglobin

PCV: Packed Cell Volume

WBC: White Blood Cell

RBC: Red Blood Cell

Table 2: Weekly effect of Lead Toxicity on Hemoglobin (g/dl)

Treatment(mg/kg)	Week2	Week4	Week6	Week8
In Aqueous solution				
50	10.20	11.10	12.00	10.10
100	11.30	9.70	10.20	10.60
150	10.24	11.70	11.30	10.20
Mixed in Feed				
50	11.12	11.05	10.18	10.35
100	10.15	10.20	11.70	10.24
150	11.20	10.35	10.24	11.10
Control	12.60	12.50	12.50	12.60

Table 3: Weekly effect of Lead Toxicity on Packed Cell Volume (%)

Treatment(mg/kg)	Week2	Week4	Week6	Week8
In Aqueous solution				
50	40.10	39.60	41.10	40.11
100	40.60	35.10	37.20	35.40
150	38.80	36.20	39.30	40.30
Mixed in Feed				
50	37.30	40.12	40.10	39.10
100	32.40	39.15	38.20	40.12
150	40.05	38.30	37.15	38.06
Control	45.30	43.60	45.30	43.60

Table 4: Weekly effect of Lead Toxicity on WBC ($\times 10^9/L$)

Treatment(mg/kg)	Week2	Week4	Week6	Week8
In Aqueous solution				
50	15.10	16.32	17.81	16.96
100	14.83	17.20	13.40	15.20
150	14.98	17.81	15.56	14.37
Mixed in Feed				
50	18.11	17.13	18.65	17.32
100	19.11	17.02	16.35	18.24
150	18.32	15.86	18.02	16.28
Control	20.12	20.50	20.50	20.12

Table 5: Weekly effect of Lead Toxicity on RBC ($\times 10^{12}/L$)

Treatment(mg/kg)	Week2	Week4	Week6	Week8
In Aqueous solution				
50	7.30	6.93	7.08	7.02
100	6.37	7.03	6.89	6.20
150	6.43	6.38	7.10	6.88
Mixed in Feed				
50	6.73	5.90	6.79	7.12
100	7.08	6.08	6.18	6.25
150	6.20	6.10	6.30	6.73
Control	8.10	7.92	8.10	7.92

DISCUSSION:

In particular, haemoglobin concentration, PCV, and RBC counts decreased with increasing lead exposure, while alterations in WBC counts suggested immune response activation associated with lead toxicity, suggesting anaemia and immune response activation due to lead toxicity. Flora *et al.*, (2008) in his research studies opined that the changes in hematological parameters suggest lead toxicity-induced anemia and immune response activation. Mishra and Singh (2013) opined that Decreased hemoglobin, PCV, and RBC counts indicate impaired erythropoiesis, possibly due to lead's inhibition of heme synthesis enzymes. Increased WBC counts may indicate an inflammatory response to lead-induced oxidative stress. The result of the study aligns with the findings of Generalova, *et al.*, (2025) in which Lead toxicity significantly impacts the hematopoietic system, causing anemia by interfering with heme synthesis and reducing erythrocyte lifespan. The reduction in hemoglobin concentration and RBC count observed in this study may be attributed to lead-induced inhibition of enzymes involved in heme biosynthesis, particularly delta-aminolevulinic acid dehydratase (ALAD), as well as oxidative damage to erythrocyte membranes. Increased oxidative stress may also contribute to shortened erythrocyte lifespan and impaired hematopoiesis.

However, some previous studies have reported less pronounced hematological alterations following low-dose lead exposure, possibly due to shorter exposure duration, differences in animal strain, or variations in environmental conditions.

A major strength of this study was the comparison of two different exposure routes (aqueous and feed-based administration), which provided broader insight into the hematotoxic effects of chronic lead exposure.

A one-way ANOVA was conducted to examine the effect of lead toxicity on the hematological indices of albino rats. The results revealed that lead exposure produced statistically significant effects on all parameters measured Haemoglobin ($F(2,4) = 49.14$, $p = 0.002$), PCV ($F(2,4) = 13.44$, $p = 0.017$), WBC ($F(2,4) = 29.62$, $p = 0.004$), and RBC ($F(2,4) = 21.06$, $p = 0.008$). Post hoc analysis using the Tukey HSD test showed that for each of these indices, the Control group differed significantly from both the Low and High lead exposure groups ($p < 0.05$), indicating that lead toxicity markedly altered the hematological parameters.

It was observed that there was a statistically significant alteration ($P < 0.05$) in the hematological indices of the albino rats when compared to that of the control (Table 1). However, the effect of the different dose levels of lead on the hematological parameters showed some differences. The result from Weekly effect of Lead Toxicity on Hemoglobin (g/dl) showed that there was a significant variation in Haemoglobin level among individual rats. This may be due to factors such as genetics, health status, environmental factors (temperature, stress etc), nutrition and diet. The effect of different concentrations of lead toxicity on Packed Cell Volume (PCV) which revealed significant variation among individual rats. This variability may be attributed to various factors, including genetics, health status, environmental factors (such as temperature and

stress), nutrition, and diet, as individual differences in these aspects can influence hematological responses to lead exposure (Ihedioha and Okoye 2012). Also there was a significant variation in White Blood Cell (WBC) levels among individual rats, which may be attributed to factors such as genetics, health status, environmental factors (e.g., temperature, stress), nutrition, and diet, influencing immune responses (Adeyemi and Akanji. 2011). Moreover, it was observed that there was a significant variation in Red Blood Cell (RBC) levels among individual rats, with a reduction in RBC counts observed from week 2 to week 8 in all treatment groups compared to the control. This decrease may be attributed to factors such as genetics, health status, environmental factors (e.g., temperature, stress), nutrition, and diet, which can influence erythropoiesis and RBC survival (Ihedioha and Okoye, 2012).

Limitations:

This study had several limitations. The sample size was relatively small, which may limit the generalizability of the findings. Oxidative stress biomarkers and histopathological examinations were not assessed. In addition, the study did not evaluate sex-specific differences in hematological responses to lead exposure. Future studies involving larger sample sizes and molecular analyses are recommended.

Abbreviations:

Hb – Hemoglobin
PCV – Packed Cell Volume
WBC – White Blood Cell
RBC – Red Blood Cell
ROS – Reactive Oxygen Species
ALAD – Delta-aminolevulinic acid dehydratase

CONCLUSION:

Chronic lead exposure significantly altered hematological parameters in albino rats, including reductions in hemoglobin concentration, packed cell volume, and red blood cell count, with associated changes in white blood cell levels. These findings suggest dose-dependent hematotoxic effects of lead exposure and highlight the importance of monitoring hematological indices in populations at risk of chronic lead exposure.

Conflict of Interest:

The authors declare that there are no conflicts of interest regarding this study.

Funding Statement:

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability Statement:

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES:

1. Adetunji VO, Oyebamiji AK, Afolayan SO. Heavy metal contamination of animal feed and feedstuffs. *J Environ Sci Health B*. 2020;55(1):34–43.
2. Adeyemi OS, Akanji MA. Biochemical and hematological changes in rats exposed to lead acetate. *J Med Sci*. 2011;11(3):155–161.
3. Adewuyi GO, Adewuyi AO. Lead exposure in Nigerian communities: A review of the current state of knowledge. *J Environ Health Res*. 2018;18(1):1–12.
4. Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Lead. Atlanta, GA: U.S. Department of Health and Human Services; 2020.
5. Ekeh FN, Ikele CB, Obiezue R. The effect of lead acetate on the testes of male albino rats. *Adv Life Sci Technol*. 2015;38:1–8.
6. Flora SJS, Mittal M, Mehta A. Heavy metal induced oxidative stress and its possible reversal by chelation therapy. *Indian J Med Res*. 2008;128(4):501–523.
7. Garza A, Vega R, Soto E. Cellular mechanisms of lead neurotoxicity. *Med Sci Monit*. 2006;12(3):RA57–RA65.
8. Generalova A, Davidova S, Satchanska G. The mechanisms of lead toxicity in living organisms. *J Xenobiot*. 2025;15(5):146.
9. Gurer-Orhan H, Sabir HU, Ozgunes H. Correlation between clinical indicators of lead poisoning and oxidative stress parameters in controls and lead-exposed workers. *Toxicology*. 2004;195(2–3):147–154.
10. Hassan MA, Ali EH, Abo-Elenein SA. Lead-induced oxidative stress and lipid peroxidation in rat brain. *J Biochem Mol Toxicol*. 2020;34(1):e22432.
11. Hoff J. Methods of blood collection in the mouse. *Lab Anim*. 2000;29(10):50–51.
12. Ihedioha JE, Okoye COB. Effects of lead exposure on hematological and biochemical parameters in rats. *J Environ Sci Health A*. 2012;47(13):1955–1963.
13. Kilkenny C, Browne WJ, Cuthill IC, Emerson M, Altman DG. Improving bioscience research reporting: The

- ARRIVE guidelines for reporting animal research. *PLoS Biol.* 2010;8(6):e1000412.
14. Lakshmi EV, Sangeetha R, Venkateswarlu S. Lead toxicity: A review on exposure, health effects, and prevention. *J Environ Sci Health C.* 2020;38(2):113–130. doi:10.1080/10590501.2020.1741572
 15. Li M, Li X, Wang J. Lead exposure and cardiovascular disease: A systematic review and meta-analysis. *Environ Res.* 2022;204:112345.
 16. Mishra KP, Singh VK. Immunomodulatory effects of lead and its interaction with other environmental stressors. *J Immunotoxicol.* 2013;10(2):133–141.
 17. National Research Council (NRC). *Guide for the Care and Use of Laboratory Animals*. 8th ed. Washington, DC: National Academies Press; 2011.
 18. Needleman H. Lead poisoning. *Annu Rev Med.* 2004;55:209–222.
 19. Nriagu JO. Lead exposure and toxicity: Mechanisms and health effects. *J Environ Sci Health C.* 2011;29(1):1–18. doi:10.1080/10590501.2011.556980
 20. Ogbu SI, Okechukwu EI. The effect of storage temperature prior to separation on plasma and serum potassium. *J Med Lab Sci.* 2001;10:1–4.
 21. Oguntimehin I, Oyebamiji AK, Afolayan SO. Environmental pollution and its effects on human health. *J Environ Sci Health C.* 2022;40(1):1–15.
 22. Occupational Safety and Health Administration (OSHA). *Lead in Construction*. U.S. Department of Labor; 2020.
 23. Patrick L. Lead toxicity, a review of the literature. Part I: Exposure, evaluation, and treatment. *Altern Med Rev.* 2006;11(1):2–22.
 24. Pourret O, Bollinger JC, Hursthouse A. Heavy metal: A misused term? *Acta Geochim.* 2021;40(3):466–471.
 25. Robinson JP, Wallace MJ. Hematological methods and automated analyzers in laboratory animals. *Vet Clin Pathol.* 2013;42(1):15–28.
 26. Sanders T, Liu Y, Buchner V, Tchounwou PB. Neurotoxic effects and biomarkers of lead exposure: A review. *Rev Environ Health.* 2009;24(1):15–45.
 27. World Health Organization (WHO). *Lead poisoning and health*. Geneva: WHO; 2017.
 28. Percie du Sert N, Hurst V, Ahluwalia A, et al. The ARRIVE guidelines 2.0: Updated guidelines for reporting animal research. *PLoS Biol.* 2020;18(7):e3000410.
 29. Xu J, Lian LJ, Wu C, Wang XF, Fu WY, Xu LH. Lead induces oxidative stress, DNA damage and alteration of p53, Bax and Bcl-2 expressions in mice. *Food Chem Toxicol.* 2008;46(5):1488–1494.
 30. Needleman HL, Gatsonis CA. Low-level lead exposure and the IQ of children: A meta-analysis of modern studies. *JAMA.* 1990;263(5):673–678.
 31. Farina M, Rocha JBT, Aschner M. Oxidative stress and antioxidant defense in lead-induced toxicity. *Toxicol Appl Pharmacol.* 2013;267(3):211–220.
 32. Bellinger DC. Very low lead exposures and children's neurodevelopment. *Curr Opin Pediatr.* 2008;20(2):172–177.
 33. Wang L, Wang H, Li J, Chen D, Liu Z. Chronic lead exposure induces hematological and biochemical alterations in experimental rats. *Environ Toxicol Pharmacol.* 2021;85:103650.
 34. Al-Saleh I, Shinwari N, Mashhour A, Mohamed GED. Heavy metal concentrations in maternal and cord blood and placenta associated with anemia. *Environ Geochem Health.* 2011;33(1):1–15.
 35. Needleman HL. The removal of lead from gasoline: historical and personal reflections. *Environ Res.* 2000;84(1):20–35.
 36. Lanphear BP, Hornung R, Khoury J, et al. Low-level environmental lead exposure and children's intellectual function: an international pooled analysis. *Environ Health Perspect.* 2005;113(7):894–899.