

One Health: Children, Waterfowl, and Lead Exposure in Northwestern Nigeria

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The One Health concept focuses on the interrelationship between the health of humans, animals, and the environment. There is a delicate balance among these relationships, and when an imbalance exists, the effects can be catastrophic. Such an imbalance occurred in 2010, when elevated lead exposure in rural communities in northwestern Nigeria resulted in the deaths of an estimated 400 children younger than 5 years in a 12-month period. Before the children became ill, waterfowl began to die in great numbers, a connection that would not be realized until much later. This review covers toxicodynamics and the neurotoxic effects of lead in the developing central nervous system, the role that animals can play in recognizing lead exposure and contamination, and environmental sources of lead exposure. The experiences in Nigeria may be especially pertinent to the emerging problems associated with lead exposure and poisoning in the United States.

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The One Health concept focuses on the complex interrelatedness of the health of humans, animals, and the environment.¹ When balance in these relationships is disrupted, the effects can be devastating.

In the winter of 2010, physicians with Médecins Sans Frontières were screening for meningitis in northwestern Nigeria when they observed a higher than expected number of childhood illnesses and deaths in 4 villages.² Most of the illnesses and deaths occurred in children younger than 5 years. Symptoms included vomiting, abdominal pain, headache, and convulsions. Initial treatment attempts included antimalarial and antibiotic therapy but were unsuccessful. It was later recognized that all of the sick children had come from villages engaged in small-scale artisanal gold mining activities (ie, unregulated subsistence mining). Subsequent blood sampling revealed blood lead levels (BLLs) ranging from 168 to 370 $\mu\text{g}/\text{dL}$.² The Centers for Disease Control and Prevention recommends intervention when BLL is greater than or equal to 5 $\mu\text{g}/\text{dL}$.³ An estimated 400 children died of lead poisoning in total, with a single village reporting the death of 30% of children younger than 5 years in a 12-month period.² Surveys conducted after the 2012 report by Dooyema et al² indicated that an entire region of northwestern Nigeria was contaminated with lead and that 1500 to 2000 children needed treatment.⁴

The deaths of large numbers of nearby waterfowl and livestock provided an early but missed warning. Approximately 4 months before the children began dying of lead poisoning, inhabitants of the most-affected villages noticed a nearly 100% mortality rate of ducks that lived in and around nearby ponds. It was later found that the few surviving ducks in less-contaminated villages all had a BLL at least 5 $\mu\text{g}/\text{dL}$.⁵ The ducks had likely died of lead poisoning.

The present review highlights the One Health concept as it pertains to this event in northern Nigeria in which toxic levels of lead exposure in family dwellings, community well water, and nearby ponds led to the mass illness and death of waterfowl, livestock, and people. In addition, the osteopathic approach to the health of the whole patient, which includes a patient's environment, is emphasized alongside the One Health concept.

Human Health

Lead is a nonessential and toxic metal that ranks second on the Priority List of Hazardous Substances compiled by the Environmental Protection Agency and the Agency for Toxic Substances and Disease Registry.⁶ Although lead causes multiple adverse health effects, including decreased fertility and peripheral neuropathy,³ we focus on the toxic effects of lead in the central nervous system (CNS), especially during early childhood development.

There is no safe level of lead exposure in children; the recommendation for medical intervention, not necessarily chelation therapy, in children was lowered in 2016 from 10 $\mu\text{g}/\text{dL}$ to 5 $\mu\text{g}/\text{dL}$.³ National Health and Nutrition Examination Survey (NHANES) data from 1999-2006 revealed that 8.4% of children in the United States had BLL greater than or equal to 5 $\mu\text{g}/\text{dL}$.⁷ The primary cause of death in children with severe lead poisoning (BLL 70-100 $\mu\text{g}/\text{dL}$), which is relatively rare in the United States, is encephalopathy

characterized by epigastric pain, vomiting, and convulsions.⁸ Much more common toxic effects of childhood lead poisoning are behavioral and intellectual deficiencies. A child's IQ declines 2 to 3 points per 10 $\mu\text{g}/\text{dL}$ increase in BLL.⁹ In addition, behavioral inattention, anxiety, hyperactivity, and impulsivity disorders have been positively associated with elevated BLL.¹⁰

Lead is particularly neurotoxic during fetal development and during the first 6 months after birth because the fetus and infant lack a completely formed blood-brain barrier. Inside the CNS, lead accumulates in glial cells such as astrocytes, causing dysfunction and toxicity.¹¹ In addition, lead interferes with synaptic plasticity, which results in impaired memory and learning by altering the expression of glutaminergic receptors.¹²

Along with exerting direct effects on the blood-brain barrier and CNS, lead also inhibits ferrochelatase and δ -amino levulinic acid, which results in microcytic hypochromic anemia.¹³ An important consideration is that other causes of anemia (eg, iron deficiency) may enhance the adverse hematologic effects of lead. For example, the most common type of anemia in the United States is due to iron deficiency, with a prevalence of 8% in infants and children aged 9 months to 30 months. Seven percent to 20.5% of children aged 1 to 3 years are considered iron deficient.¹⁴ Iron intake below the recommended daily allowance was found in 26.1% of children aged 1 to 2 years in the United States.¹⁵ Iron deficiency is detrimental to the development and function of the CNS and is associated with long-lasting mental and behavioral deficits.^{16,17} Furthermore, childhood anemia is associated with elevated BLL greater than or equal to 5 $\mu\text{g}/\text{dL}$.¹⁸

For any child with BLL greater than or equal to 5 $\mu\text{g}/\text{dL}$, the first step in treatment is to remove the patient from the source of lead exposure.³ An additional and at times controversial practice is the use of chelation agents to facilitate the excretion of lead and other metals from the body. Shortly after lead poisoning was discovered in northwestern Nigeria, children with BLL

greater than or equal to 45 $\mu\text{g}/\text{dL}$ underwent chelation therapy. The metal chelator dimercaptosuccinic acid was given at an oral dose of 250 to 750 mg, depending on age, along with zinc and iron supplementation.¹⁹ Although oral chelation therapy was effective and saved the lives of thousands of children in this instance of lead poisoning, it is important to note that chelation therapy is only advised when BLL is greater than or equal to 45 $\mu\text{g}/\text{dL}$.³ For patients with BLL less than 45 $\mu\text{g}/\text{dL}$, or if poisoning is caused by other metals, such as cadmium, chelation therapy may be detrimental and unadvised because of the potential for redistribution of metals in the body after chelation therapy.²⁰ Although increased renal excretion of metals may occur immediately after chelation therapy as evidenced by increased urinary metal content, metals may simultaneously redistribute to the kidney or CNS if the chelator is especially lipophilic.²⁰

One of the central tenets of osteopathic philosophy is the body's intrinsic ability to self-heal,²¹ but the long-term effects of lead exposure on behavior and cognition may be irreversible.¹² However, some evidence suggests that some specific behavioral deficits linked to lead poisoning may resolve over several years.²² In a study comparing spatial learning using a water maze, rats exposed to lead at birth performed as well as rats that were not exposed, but only if the animals were housed socially with "enrichment" (eg, tubes and nesting material).²³

Animal Health

Because of inherent physiologic similarities, lead is also toxic to nearly all animal species. Specific to waterfowl, lead poisoning may be acute or chronic, depending on the animal's size, level of environmental contamination, and feeding habits. In the United States, lead toxicity in waterfowl has often been associated with ingestion of lead pellets and bullets, lost fishing sinkers, and lead tackle.²⁴ Clinical signs in poisoned birds vary but may include weight loss and emaciation, weakness and lethargy, blindness, seizures, and poor growth and development. Many affected birds often

succumb to predators, which can result in high levels of lead ingestion by the predator.²⁴

In the aftermath of the Nigerian lead exposure incident, surveys of affected villagers were conducted regarding the health of nearby livestock and other animals before and during the period of lead exposure. The survey found that in 2009, nearly all ducks in the affected villages exhibited unusual behaviors, such as "salivation, convulsions, and hyperesthesia," before death, as did sheep and goats.⁵ The early and overt toxic effects of lead in the birds was likely due to increased lead exposure and not to increased sensitivity to lead toxicity, as birds with higher BLL than humans have fewer adverse health effects.²⁵ The increased exposure to lead may have been due to unique aspects of avian biology. Birds, especially waterfowl, have a muscular stomach (gizzard) that helps to grind and break up food. Therefore, the regular ingestion of sand or gravel (gastroliths or grit) is required to facilitate food breakdown in the gizzard. The waterfowl in Nigeria were likely consuming lead-contaminated gold ore waste material (small rocks and grit) in the nearby ponds. A similar example of mass poisoning of wildlife with lead occurred in the Coeur d'Alene River basin in Idaho. River sediment highly contaminated with lead for approximately 30 miles downstream from mining and smelting operations was the source of elevated BLL in local waterfowl.²⁵

Outside of mining activity, the single most significant source of lead detected in wild birds is shotgun pellets or bullet fragments. A 2009 report noted that deaths attributed to lead exposure in bald eagles in Wisconsin peaked in December, coinciding with the hunting season.²⁴ The authors concluded that lead exposure occurred when the eagles consumed bullet fragments left in discarded gut piles from field-dressed animals. Although the United States has banned lead-based pellets to hunt waterfowl since 1991, lead pellets are still permitted for hunting of other game animals. Moreover, other countries have been slow to act. Slovakia was to have phased out lead pellets in waterfowl hunting by 2015. In southern Europe in

1989 and 1990, the prevalence of lead pellet ingestion in mallard ducks was as high as 36.4%.²⁶ Although some effects of lead may be reversible, the behavior deficits resulting from a single intraperitoneal dose of lead in 2-day-old herring gull chicks has been reported to cause long-lasting effects, including impaired walking and feeding and difficulty thermoregulating (eg, moving to shade during the day).²⁷ All of these effects would reduce chick viability in the wild.

In 2006, residents of the small seaside town of Esperance, Australia, witnessed massive deaths of native bird species, with the total number of dead birds exceeding 9000.²⁸ This observation initiated investigations to identify the cause of the deaths based on elevated organ lead levels in some birds. Lead carbonate, a more absorbable form of lead, was present in ore from an inland mine that had been transported through Esperance to the port. Strong winds coming from the ocean carrying fine dust characteristic of the particular ore contaminated the town.^{29,30} The source of lead exposure was identified early, owing to the reported bird deaths, and practices were altered, such as rerouting trains and not drinking rain water. Subsequent surveys showed a mean BLL of 7.5 $\mu\text{g/dL}$ in children aged 6 years or younger.²⁸ Although that BLL is considered high, none of the children was in danger of death due to encephalopathy.

Environmental Health

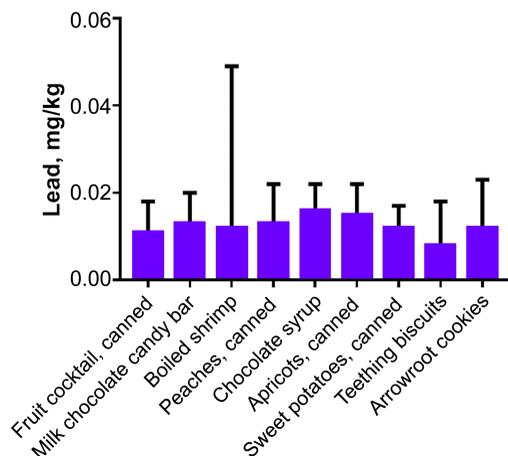
Some countries consider the practice of small-scale artisanal gold mining beneficial in impoverished communities where people have little opportunity to earn money otherwise.³⁰ An estimated 15% of the world's gold supply comes from this practice, which typically occurs inside family compounds. An estimated 10 to 15 million people, 3 million of whom are women and children, are miners in these communities.³⁰ Although methods differ, the most common type of gold ore processing is to first crush the ore into pebble-sized pieces using hammers and then grind the smaller pieces using a gasoline-powered flour mill that is also used in food processing. Both processes produce a large amount of

lead-contaminated dust, which then contaminates grains processed for consumption.³¹

The pulverized ore undergoes sluicing and washing in nearby streams or ponds. Elemental mercury is then combined with the washed and pulverized ore to form mercury-gold amalgams that are later heated to vaporize the mercury, leaving a crude form of "sponge" gold for further processing. This gold ore processing is so ubiquitous that approximately 1400 tons of mercury were used for gold mining in 2011 alone.³⁰ In northwestern Nigeria in 2010, the gold ore deposit that was being mined exceeded 10% in lead content.³¹ While it is easy to understand the economic impact of this form of gold mining in the developing world, it is also important to recognize the negative effect on the environment and, ultimately, on human health.

Even though the example in Nigeria focuses on a localized incident of lead contamination in a developing nation, lead poisoning is an important issue in the United States and other developed nations. Several highly publicized instances of lead poisoning in urban areas, such as Flint, Michigan,³² and Northwest Indiana,³³ have highlighted the severity of the problem. In Flint, the lead exposure resulted from changing the water supply from a clean source to a polluted source (the Flint River).³² In Northwest Indiana, exposure resulted from residual contamination when a housing development was built on the site of an old lead-processing plant.³³

Most cases of lead poisoning in the United States involve the consumption of contaminated food or water, ingestion of lead-containing paint chips, or inhalation of lead-contaminated dust. The **Figure** shows the US Food and Drug Administration Total Diet Study's element findings with regard to the average lead content of select foods.³⁴ By comparison, the Environmental Protection Agency's action level for lead in drinking water is 15 ppb, or 0.015 mg/kg. Many of the foods with elevated lead levels are processed or canned. The source of lead in chocolate consumer products is not the raw materials but the lead-based machinery used to process the chocolate, with lead leaching from machinery into the final chocolate product.³⁵ As the **Figure** shows, 2 food items intended for



Figure

Levels of lead in food reported by the Food and Drug Administration Total Diet Study.³⁴

consumption by infants were relatively high in lead content: teething biscuits and arrowroot cookies. Another source of lead exposure is folk or Ayurvedic herbal medicine. In one case study, a 26-year-old man was given a lead-containing herbal remedy for back pain while visiting India; shortly after returning to the United States he presented to the emergency department with epigastric pain, nausea, and vomiting, and he was noted to be anemic and to have a BLL of 94.8 $\mu\text{g}/\text{dL}$.³⁶

These examples highlight the dangers of environmental metal toxicity that may result years or even decades after the initial contamination. They may also explain why the top 3 environmental toxicants on the ATSDR's Substance Priority List are arsenic, lead, and mercury.⁶

One Health

The 2010 epidemic of childhood lead poisoning in Northwestern Nigeria is just one example showing the aftermath of human activity in the form of small-scale artisanal gold mining and how changes in animal health and behavior can serve as early indicators of major environmental hazards before they have detrimental effects on human health. The eventual linking of the children's illness and deaths to lead exposure by Médecins sans

Frontières was serendipitous, and subsequent interventions were not implemented early enough.

This case also serves as a model in which the One Health concept can be illustrated. To prevent this kind of widespread health catastrophe, regional or global systemic surveillance, part of a true One Health initiative, will need to be instituted by capable and resourceful entities. In this respect, the United States is in a position to spearhead initiatives to incorporate animal health as part of surveying human health. The Centers for Disease Control and Prevention oversees NHANES, which is one of the most comprehensive and extensive health surveys in the United States. Obvious human health topics covered in the NHANES questionnaire include smoking, alcohol use, sexual behavior, and physical activity, as well as topics less directly related to health, such as occupation, income, and health insurance status. However, no questions are asked about possible exposure to animal species that may transmit zoonotic diseases (eg, pigs and trichinosis and pork tape worm; mosquitos and arboviral infections) or observed local wildlife illnesses and deaths in large numbers.

To begin to benefit from the One Health concept and gain a better understanding of the relationship between human and animal health, questionnaire topics related to exposure to animals and zoonotic diseases and observed mass animal illness and deaths should be included in future NHANES questionnaires. Although the National Outbreak Reporting System collects reports on waterborne, foodborne, and enteric disease outbreaks due to contact with human, animal, or environmental sources, local, state, or federal agencies are not required to use this system to report outbreaks. Regardless of the agency involved or the instrument used, ongoing surveillance of human, animal, and environmental pathogens and toxins can provide early warnings in similar instances of environmental exposure in the future. In the current case, although the recognition by the Médecins sans Frontières was fortunate, it was too late for effective interventions to be implemented.

Physicians must be constantly vigilant to identify evidence of an illness that seems out of the ordinary and could be caused by exposure to environmental toxins. Osteopathic physicians in particular are trained to consider multiple aspects of their patients' health, including their environment. To take full advantage of the One Health concept, the initiative should be introduced at the level of medical education. Certainly, the current emphasis on interprofessional education is a major step in the right direction. However, to fully exploit these educational gains, interprofessional education must evolve into interprofessional practice for true One Health interventions to occur.

It is worth noting that the preparation of this review revealed a disconnect between the human and animal literature concerning lead poisoning. For example, many of the reports published between 2000 and 2010 on lead poisoning in wildlife and other animal species do not show up in PubMed searches.^{23-25,28} We found that using the Google.com search engine was a more useful alternative. However, the creation of a search engine that pulls published reports on both humans and wildlife could advance the One Health concept and lead to more research on human-animal-environmental interrelationships.

Conclusion

Human activity can result in severe damage to the immediate and global environment, leading to increased morbidity and mortality among animals and, ultimately, humans themselves. Acquiring the knowledge and skills necessary to recognize the effects among humans, animals, and the environment and to intervene appropriately under the One Health initiative should be nurtured in the education programs of the health professions. With its emphasis on holistic patient care, the osteopathic medical profession is well positioned to be a leading advocate for the One Health initiative. However, it is effective interprofessional practice that is ultimately necessary for effective One Health implementation and interventions.

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