Ball and chain: The global burden of lead poisoning

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Lead, the 82nd element in our periodic table, has accompanied humankind throughout the millennia of our history and development. As a ubiquitous heavy metal, lead is used in multiple applications and nine billion tons continue to be extracted globally every year. Although the United States has succeeded in limiting lead exposure among its own citizens by banning the use of lead in gasoline and household paint, while instituting improved working conditions for those who are exposed to lead in the workplace, the battle against lead is not won. In addition, it continues to plague the rest of the world today; the United States has played an increasing role in the world’s exposure to lead and plans to stop are currently stalled. The year 2011 marked the centennial celebration of the life’s work of Dr. Alice Hamilton in exposing lead poisoning among industrial workers in Chicago, Illinois. Her legacy provides us with the opportunity to look back and reevaluate our leaded history in the US. It also reminds us that there is more to be done to mitigate lead poisoning both domestically and in the developing world.

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From the daily grind of the Roman Empire to our ongoing modern-day efforts in electronic waste recycling, lead has stood the test of time in remaining entwined in human life, due to its ubiquity, malleability, corrosion-resistance, and even its taste. Here we traipse through time to explore the fine wines of yesteryear, the courageous few who spoke against the toxic trades, and the current lead exposures that continue unfettered on foreign shores.

In 6500 BCE, lead was first mined in Anatolia, located in modern-day Greece. Lead was a byproduct of silver mining that was valued for its corrosion-resistance, malleability, and easy availability. Vitruvius, the famous architect of the Roman Empire, was cautious with its use, stating, “For when, in casting, the lead receives the current of air, the fumes from it occupy the members of the body, and … rob the limbs of the virtues of the blood.” Water pipes, reservoirs, and the architecture of the day contained high lead content. In the kitchen, Romans boiled their wine to make sapa, concentrated grape syrup that served as both a preservative and sweetener. Bronze was quickly rejected; Roman winemaker Columella writes “in the boiling, brazen vessels throw off copper rust which has a disagreeable flavor” but leaden vessels did not. Although hotly debated, lead poisoning is considered a potential contributor to the downfall of the Roman Empire due to possible reproductive and neurocognitive dysfunction of its leaders, including Julius Caesar.

Multiple epidemics of the colic of Poitou (also known as colica Pictonum, the West-Indian dry gripes, the Devonshire colic, colica convulsiva, and wine disease) inflicted Europe and the Americas from the Roman ages to the 18th century. The “pestilential contagion” that was described by Byzantine physician Paul of Aegina misled physicians, who had considered it an endemic infectious disease in the Americas and a disease of frost-damaged grape harvests in Europe. Without refrigeration, European society was known to use litharge like the Romans used sapa. Litharge is the solid foam, or lead oxides, that results from lead, silver or gold refining.

The grape harvests of Maunder Minimum, a period of unusually bleak weather between 1645 AD and 1715 AD, required considerable wine “correcting”. This resulted in multiple epidemics in the imperial city of Ulm in Southern Germany. Eberhard Gockel, the city physician of Ulm, realized that the monks under his medical care had familiar symptoms. He was an avid admirer of Samuel Stockhausen, a German physician who published a 1656 book on mining illness, which described the monks’ very own disease process. After sharing some wine offered by his patients, Gockel “was attacked by the most atrocious colic pains and a terrible fever, which did not leave [him] for half a year.” The attentive physician sought the recipe from the same wine dealer and found 16 g of lead in 1 L of litharge—diluting it to sweeten wine would result in a lead concentration of 70 mg/L. Ultimately, Gockel discovered an assay to detect lead-contaminated wine by using sulfuric acid to precipitate lead sulfate out of solution. This assay was quite sensitive—more recently, it was found to detect a concentration of 10 mg/L of lead, a worthy test to predict wine disease in Gockel’s day.
The father of occupational medicine, Bernardo Ramazzini, is believed to be the first to recognize occupational lead poisoning. His 1713 treatise, “De Morbis Artificum Diatriba (Diseases of Workers)” discusses the cause of illnesses associated with pottery-glazing and portrait painting. He writes, “When they need roasted or calcined lead for pots, they grind the lead in marble vessels … During this process, their mouths, nostrils, and the whole body take in the lead poison.” The disease was progressive; “their hands become palsied, then they become paralytic, splenetic, lethargic, and toothless.” He mentions that all his painting acquaintances were sickly because of “the colors that they handle and smell constantly, such as red lead (minium), cinnabar, and white lead (cerussa).”

The use of lead in printed type pieces for the printing press began in the Middle Ages after wooden blocks were found to be less durable. Benjamin Franklin recalls in a letter to his friend in 1786, how he warmed the leaden type pieces near the fire. He wrote that a co-worker “advis’d me not to do so, telling me I might lose the Use of my Hands by it, as two of our Companions had nearly done, one of whom that us’d to earn his Guinea a Week could not then make more than ten Shillings and the other, who had the Dangles, but Seven and sixpense.” He also discusses occupations associated with lead exposure, as revealed by a list of patients he had taken from a Parisian hospital known to heal those with the “dry gripes.”

In the mid-1800s, Sir John Franklin, an admiral of the British navy, set sail with 128 men and two highly equipped ships for the fabled Northwest Passage, a route that would connect the Atlantic to the Pacific via modern-day Canada, in order to have easier access to the spices of the Silk Trade. The crew never returned to Great Britain and search parties were unsuccessful in determining the cause of their apparent demise. The tin can supply, a fairly new technological advance at the time, may have been the culprit. The remains of the crewmen lay preserved in the ice for over a century before researchers found toxic levels of lead in their tissue matching the lead content of the solder of the tin cans.

This was one of many lead epidemics that occurred during the Industrial Revolution. Throughout Australia, the United States, France and Great Britain, occupational exposures to lead resulted in disability and death. In 1892, an ophthalmologist and a pediatrician team investigated why the children of Brisbane, Australia were suffering from a deadly affliction. Dr. J. Lockhart Gibson had his own house examined and high lead content from paint was discovered. This prompted local legislation to limit lead in paint, but it also piqued the interest of one physician in the United States, Dr. Alice Hamilton (Fig. 1). She had been researching industrial medicine in Europe and moved to Hull House in Chicago, Illinois where the workers of the toxic trades resided, to develop policies promoting safer workplace practices. In her mission, there was one battle that she could not win—the battle to prevent the use of tetraethyl lead in gasoline.

In 1921, Thomas Midgley, working under Charles F. Kettering (Fig. 2) of General Motors Research Company, discovered that tetraethyl lead was an effective anti-knock agent, and by 1923, leaded gasoline was being sold. The new gasoline was highly marketed with the omission of “lead” in its name due to the public’s stark opinion of that term. Dr. Alice Hamilton stood her ground against the advertising campaign, and is known to have said to Kettering in private conversation, “You are nothing but a murderer.” A year later, the first case reports emerged of workers in the tetraethyl lead plants falling ill. The “loony gas” presented a form of inorganic lead to these workers, which easily crossed the blood–brain barrier; many of its victims succumbed to insanity or death. Although sales were suspended for 1 year, subsequent safety analyses were funded by the lead industry. Dr. Robert Kehoe, Ethyl Corporation’s chief medical consultant, stated that leaded fuels were not a health threat because lead is naturally found in the human body. Independent research, such as a study conducted by Randolph Byers in 1943 that found that lead-exposed children had behavioral...
problems, was silenced—Byers’ was threatened with a lawsuit.

Dr. Alice Hamilton died in 1970 without knowing that public health would eventually have the final say. Dr. Herbert Needleman and Dr. Philip Landrigan’s research evaluating blood lead levels (BLL) and child IQ made the connection between environmental lead contamination and neurocognitive deficits in children, which was the final straw. The U.S. Environmental Protection Agency (EPA) started a phase-out plan for leaded gasoline and lead paint in 1978. Adult BLL have dropped by 88% since the ban on leaded products, a true public health success story (Fig. 3). Although the measures are in place, it is estimated that three billion tons of lead still exist in 38 million U.S. homes built prior to 1980.

The Lead Contamination Act of 1988 authorized The Centers for Disease Control and Prevention (CDC) to take on the charge of eliminating childhood lead poisoning. Reducing childhood BLL remains one of the Healthy People 2020 goals. In 1991, the CDC reported the BLL of concern to initiate clinical intervention was 10 mcg/dL, but this has been refuted by recent research. Canfield et al. found that in children, for every increase in BLL of 10 mcg/dL, IQ dropped by 4.6 points. Surprisingly, the largest drop of 7.4 points was found within the group of children whose BLL was within the first 10 mcg/dL. Irreversible neurologic damage appears to occur at a lower BLL than originally thought. In January 2012, the Advisory Committee on Childhood Lead Poisoning Prevention of the CDC advised elimination of the term “blood lead level of concern” in lead policies to promote primary prevention at all BLL. This recommendation prompted the CDC to officially change their lead policy in May 2012. The reference value, which is now equivalent to the 97.5th percentile of BLL of children aged 1–5 years (currently 5 mcg/dL), should motivate physicians to investigate further for lead hazards. The CDC also calls for this reference value to be updated every 4 years based on the current pediatric population BLL distribution. The level of 45 mcg/dL remains the threshold to initiate succimer therapy in children. However, these BLL values should not be mistaken as biological thresholds of harm; there is no safe lead level. The CDC reports that 250,000 children aged 1–5 years continue to have BLL > 10 mcg/dL, but our current domestic lead issues pale in comparison to lead poisoning epidemics that are occurring in other parts of the world.

The World Health Organization (WHO) has noted the more recent evidence that any level of lead results in a detrimental health impact on children. The joint Food and Agriculture Organization/WHO Expert Committee on Food Additives withdrew provisional guidelines on the tolerable weekly intake value of lead-contaminated food because of the realization that these thresholds were insufficient to protect against lead-induced IQ loss. Although cost-benefit analysis has recently found that for every U.S. dollar (USD) spent on lead mitigation, there is a monetary benefit of up to USD $220, this information has not been transformed into action in low-income countries, where the impact of lead poisoning is most concerning. Worldwide, 16% of children are estimated to have BLL > 10 mcg/dL and with the new level for intervention beginning at 5 mcg/dL, the number of children in need of environmental analysis and mitigation strategies is staggering.

One such example is the “electronic graveyard” of Guiyu, China. The 28 villages of Guiyu had once contained flourishing rice paddy fields, but they are now the home of the largest electronic waste dump on Earth, receiving about 1 million tons of high-tech trash annually. The majority is from the United States. Every day, about 100 truckloads are dumped for processing, while 150,000 workers scavenge for reusable parts. The workers are comprised of adults and children who make about USD $1.50 a day. In Guiyu, lead content in dust samples is over 300 times higher than those collected about 30 km away. The children have 54% higher average BLL than those in the neighboring town of Chendian. Pregnancies are six times more likely to end in miscarriage. The e-waste recycling industry in Guiyu is in its 17th year without protections in place and Guiyu’s citizens continue to be poisoned in the process.

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal is a United Nations treaty dedicated to reducing the export of toxic waste between countries. Although signed into effect on March 22, 1989, the United States has yet to ratify the treaty and is free to export hazardous waste per EPA guidelines. The EPA requires that the receiving country approve waste exports 45 days prior to shipment; however, categorizing computers as lead scrap metal circumvents this rule. The EPA and the U.S. Government Accountability Office state that they are committed to ratifying the Basel Convention by the end of 2012. In the meantime, the Responsible Electronics Recycling Act (H.R. 2284) was introduced to the U.S. House of Representatives in June 2011 and has been referred to the Subcommittee on Energy and Environment. If passed, it will ban the exportation of certain electronic waste that is currently overwhelming Guiyu, China, as well as other cities in Ghana, Nigeria, India, and Pakistan. Unfortunately, the bill protects continued exportation of spent lead acid batteries, a waste stream that has become problematic for Mexico.

Although the burden of lead exposure has been reduced in the United States, it has largely been transported to foreign countries where, because of lax public health protections, physical and mental health is even more at risk. The exportation of toxic e-waste provides a free source of raw materials for the production of electronic equipment in recipient countries, but this venture becomes deleterious when these countries are inundated and lack safety standards that put the health of their citizens first. History has taught us that the ubiquity of lead makes it difficult to abate from our lives and environment, but we have also experienced the enormous capacity for improved outcomes through mitigation and education. Although the struggle to eliminate lead poisoning continues, it remains a successful public health program within the United States, and has the potential to become the same for the rest of the world as well.

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Declaration of interest

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