Global approach to reducing lead exposure and poisoning

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ABSTRACT

Lead poisoning is an important environmental disease that can have life-long adverse health effects. Most susceptible are children, and most commonly exposed are those who are poor and live in developing countries. Studies of children’s blood-lead levels (BLLs) are showing cognitive impairment at increasingly lower BLLs. Lead is dangerous at all levels in children.

The sources of lead exposure vary among and within countries depending on past and current uses. Sources of lead may be from historic contamination, recycling old lead products, or from manufacturing new products. In all countries that have banned leaded gasoline, average population BLLs have declined rapidly. In many developing countries where leaded gasoline is no longer used, many children and workers are exposed to fugitive emissions and mining wastes. Unexpected lead threats, such as improper disposal of electronics and children’s toys contaminated with lead, continue to emerge.

The only medical treatment available is chelation, which can save lives of persons with very high BLLs. However, chelating drugs are not always available in developing countries and have limited value in reducing the sequelae of chronic low dose lead exposure. Therefore, the best approach is to prevent exposure to lead. Because a key strategy for preventing lead poisoning is to identify and control or eliminate lead sources, this article highlights several major sources of lead poisoning worldwide. In addition, we recommend three primary prevention strategies for lead poisoning: identify sources, eliminate or control sources, and monitor environmental exposures and hazards.

Published by Elsevier B.V.

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1383-5742/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.mrrev.2008.03.003
1. Introduction

Lead has been mined, smelted, and used in cosmetics, internal and topical medicinal preparations, and paint pigments and glazes since early recorded history [1]. As early as the second century B.C., the symptoms of lead poisoning were described by the Greek physician, Nikander [2]. The harmful effects of lead poisoning in workers and children were described in the 19th century [3]. By the mid-1920s, studies detailed the dangers of cumulative doses of lead, the vulnerability of children, and the harm to the nervous system [3]. For years it was generally believed that children who did not die during the acute stage of lead poisoning suffered no long-term adverse health effects [4,5]. However, evidence of adverse health effects that did not meet the diagnostic criteria for neurologic disease but were associated with lower intellectual functioning began to emerge in population-based epidemiologic studies in the 1970s [6].

Despite growing evidence of adverse health effects related to lead, it is still widely used in consumer products and released into the air through combustion of coal and oil, waste incineration, and fugitive emissions during mining and smelting. Many countries have taken steps to control the use of lead. For example, lead in household paint was banned in Australia in 1920 and by international convention in 1925 [4]. The phase-out of lead in gasoline began in the mid-1970s in the United States; many other countries have also banned leaded gasoline. However, more must be done to protect people in all nations. Worldwide a large number of people are exposed, especially those in developing countries. This article will highlight adverse health effects and several sources of lead exposure reported internationally in the scientific literature since 2000. We recommend three strategies to prevent people worldwide from ever being lead poisoned.

2. Adverse health effects

Lead is a potent and pervasive neurotoxicant. The toxic effects of lead are the same regardless of the route of entry into the body, which are primarily ingestion and inhalation. Once absorbed, lead binds to erythrocytes and travels in the blood to soft tissues, such as the liver, kidneys, lungs, brain, spleen, muscles and heart. After several weeks, most of the lead moves into bones and teeth. In adults about 94% of the total amount of lead in the body is contained in the bones and teeth. About 73% of the lead in children’s bodies is stored in their bones. Lead can stay in bones for decades [7].

Lead affects virtually every organ or system in the body, and the proposed mechanisms of lead toxicity involve fundamental biochemical processes. These proposed mechanisms include lead’s ability to inhibit or mimic the action of calcium and to interact with proteins. One of the best documented mechanisms is impairment of heme synthesis which results in adverse effects not limited to the hematopoietic system. Most of the lead in blood is bound to erythrocytes [8] but plasma is the biologically active compartment which lead is available to cross cell membranes [9]. Blood-lead levels (BLLs) are related to diverse health effects, presumably because it is related to plasma lead, which exchanges with lead in critical target tissues, such as the brain, bone, erythroblasts and kidney.

The adverse health effects range from death [7] (Fig. 1) to impaired cognitive and behavioral development that can have lifelong consequences for children. Children are more susceptible than adults to the effects of lead exposure because a proportionately greater amount of the lead they ingest is absorbed, more circulating lead enters their brain, and their developing nervous system is more vulnerable to lead’s toxic effects [10]. In 1991, the Centers for Disease Control and Prevention (CDC) responded to the increasing number of studies that found adverse health effects in children at blood-lead levels as low as 10 μg/dL by issuing new guidelines. These included compiling an environmental history, educating parents about lead, and conducting follow-up for children with BLLs > 10 μg/dL [11].

Recent research demonstrates that cognitive impairment is associated with BLLs < 10 μg/dL among children [12–18], Lanphear et al. [12] analyzed data collected in NHANES III, a nationally representative sample of the US civilian population. They observed cognitive effects in children aged 6–16 years with BLLs < 5 μg/dL. Two other cross-sectional studies, one conducted in Detroit [13] and the other in Mexico City [14] tested children at age 7 years and also found an inverse relationship with BLLs < 10 μg/dL and cognitive development. In the Rochester Longitudinal Study, Canfield [15] found that children’s intellectual functioning at ages 3 and 5 years was inversely related to BLLs even when their peak BLL was <10 μg/dL. Bellinger and Needleman [16] re-analyzed data on a cohort of children in Boston whose BLLs never exceeded 10 μg/dL and found similar findings. Tellez-Rojo et al. followed a cohort of children in Mexico City and tested them at ages 12 and 24 months. The children’s BLLs did not exceed 10 μg/dL and there was a significant inverse relationship between BLL and mental and psychomotor development [17]. Lanphear et al. [18] pooled data from 7 international population–based longitudinal cohort studies that included 1333 children who were followed from birth or infancy until ages 5–10 years and found intellectual deficits in children whose BLLs never exceeded 7.5 μg/dL. Importantly, studies identified no threshold for cognitive impairment due to lead exposure in children.

One expanding area of study is the effect of maternal lead burden on fetal and child development. Because more than 90% of lead in human adults is stored in the bone [19] it can be released into the blood during times of bone resorption. One such time is during pregnancy when mobilization of maternal bone into the blood stream can expose the developing fetus [20]. Evidence that maternal bone lead can be mobilized during pregnancy has been provided by isotopic studies [21,22]. In addition, there is a strong correlation between maternal and umbilical cord blood-lead levels that indicates the transfer of lead from mother to fetus [23].

Several cohort studies have provided more evidence that prenatal exposure is associated with child cognitive development. Gomaa et al. [24] measured umbilical cord blood lead and infant bone lead and compared lead levels with this cohort’s scores on the Mental Development Index (MDI) on the Bayley scales at age 2 years. Infants with the lowest patella lead levels had higher MDI scores than infants with higher patella lead levels [24]. Because the effects produced by a neurotoxic agent depend on the timing of the exposure [25], three of the cohort studies examined timing of lead exposure during pregnancy. Hu et al. [26] studied fetal lead toxicity during each trimester of pregnancy as predictors of infant neurodevelopment. They found that fetal exposure to lead during the first trimester before the pregnancy is recognized may have a greater impact on adverse neurodevelopment later in life than exposures during the second or third trimester [26]. The Mexico City Prospective Lead Study [27] assessed the relationship of BLLs collected during the second and third trimester of pregnancy, at delivery, and at multiple points throughout childhood with IQ measured at 6–10 years of age. Higher maternal BLL at third trimester of pregnancy, especially around week 28, was associated with decreased intellectual child development, even after controlling for other prenatal and postnatal lead measurements. Wasserman et al. [28] investigated the contribution of prenatal and postnatal lead exposure to early intelligence. Blood samples were collected from pregnant women living in Kosovo from 1985 to
1986 at mid-pregnancy, delivery, and at subsequent 6-month intervals for their prospective lead study. The study participants’ infants were tested at ages 3, 4, 5, or 7 years to determine intellectual function. The findings suggested that prenatal and postnatal exposures that occur at any time during the first 7 years of life are likely to be independently associated with small decrements in later IQ scores, even after controlling for social factors [28].

Cognitive function and lead levels among adults have also been examined. Shih et al. [29] reviewed 21 studies published from 1996 to 2006 that compared markers of both recent (blood lead) and cumulative (bone lead) dose and their association with cognitive function. The association between cognitive function and bone-lead levels was consistently stronger than for BLLs among environmentally exposed older adults. In contrast, among workers with current lead exposure the association between cognitive function and BLLs was stronger than for bone levels.

Another area that has been associated with adult lead levels is cardiovascular disease. Navas-Acien et al. [30] conducted a systematic review of all observational studies through August 2006 regarding lead and cardiovascular end points. They summarized findings from seven previous reviews of lead and blood pressure, all of which reported a positive association, albeit modest, between lead exposure and blood pressure. They reviewed 30 studies that examined lead levels and clinical cardiovascular endpoints (cardiovascular, coronary heart disease, stroke mortality, and peripheral arterial disease) in both general and occupational populations. Although positive associations between lead exposure and cardiovascular disease were observed, several methodologic limitations existed.

3. Sources

The sources of lead exposures vary among and within countries depending on historic and current uses. The following section presents several sources that have been described in the recent scientific literature.

3.1. Leaded gasoline

Leaded gasoline accounted for 80–90% of airborne lead pollution in large cities where it was used worldwide [31]. Countries that have phased lead out of gasoline have reported corresponding decreases in lead concentrations in air and human blood. The decreases in population BLLs have been dramatic. For example, mean BLLs in the United States, Ontario, Canada, and the United Kingdom were reduced by >70% as lead in gasoline was reduced [32]. As more countries phase lead out of gasoline, similar findings are reported. For example, Singh and Singh [33] reviewed 15 research studies all of which measured lead in the environment and some measured human blood during different periods. The reviewers categorized the studies according to three stages of their leaded gasoline phase-out: before (before 1996), during (1996–2000), and after (2000 and after). Reductions in lead concentra-
tions were observed in tree leaves, water, air, and children's blood as lead was removed from gasoline [33]. In another study, Nichani et al. [34] assessed children's BLLs in Bombay, India, 2–3 years after the phase-out of leaded gasoline and compared their findings with results from BLLs in a study conducted by the George Foundation in 1997 (when leaded gasoline was still used in Bombay). Using similar blood-collection procedures, the study conducted before leaded gasoline was banned showed that 61.8% of children had BLLs >10 μg/dL compared with 33.2% after the phase-out [34].

3.2. Smelters

Metal smelters are another potential source of contamination for air and soil and can contribute to lead poisoning. Concerns about the health effects for people living near smelters can prompt investigations such as the study of children’s BLLs and risk factors conducted in Torreon, Mexico, in March 2001 [35]. The Met-Mex Penoles metal-processing plant, the largest in Latin America and fourth largest in the world, is located in Torreon. The mean BLL of children living there was 6.0 μg/dL and 20% had BLLs >10 μg/dL in 2001. BLLs and soil–lead levels increased in a dose–response fashion as the distance from their homes to the smelter decreased. Leaded gasoline was not considered a significant contributor to the lead levels observed in Torreon because lead had been completely phased-out from gasoline in Mexico in 1997 [36].

After smelter emissions stop, historic soil contamination can pose an ongoing threat. In June 2005, reports of symptomatic lead poisoning among refugee children in Kosovo reached the US CDC. The children most affected by the lead contamination in Mitrovica, Kosovo, were the Roma whose homes were destroyed during the war. They were relocated to refugee camps situated on land contaminated with lead and other heavy metal mining wastes near the Trepsa smelter in Mitrovica. Considerable historic contamination remains in the areas from the mining and smelting operations that occurred there for centuries. The current facility dates to the 1930s and had been the economic base for the region. Operations ceased in 1999 when routine testing of United Nations peacekeeping forces identified soldiers with elevated BLLs. This finding motivated testing of children living in the nearby refugee camps. All children had blood-lead levels >10 μg/dL, the level of concern for young children. The mean BLL was 47 μg/dL in the camps as compared to 29 μg/dL in the non-Roma children in the area [37].

3.3. Battery recycling

Informal lead-smelting operations, often operated at or near the home, can be a source of lead exposure for nearby residents. “Backyard” or “cottage” lead smelting has been described in the scientific literature for decades [38–40]. Reports of backyard smelters as a cause of lead poisoning worldwide continue. These smelters are usually unregulated and the magnitude of the problem is not documented. A 1991 Jamaica study estimated that about one third of spent lead-acid batteries in Jamaica were recycled by backyard smelting operations or by small battery repair shops scattered over the island [40]. These can be especially dangerous to workers’ families and neighbors because the work areas rarely have proper ventilation or control of worker exposure or lead release. These operations create lead emissions that then settle and contaminate nearby soil, water, and food and can result in high levels of lead exposure for families.

Other countries have also reported small secondary smelters as sources of high dose lead exposure. Paoliello and DeCapitani [41] reviewed published studies of environmental contamination in Brazil and reported that, even though leaded gasoline is banned and lead mining and primary smelting plants have closed, hundreds of small secondary battery recycling plants that create local contamination still operate. A Middle Eastern study found BLLs >10 μg/dL among 2.2% of young children in Israel, <1% in Jordan, 5.2% in West Bank, and 17.2% in Gaza. All of the children in Gaza with BLLs >10 μg/dL lived near local small smelters engaged in secondary recycling, smelting, and battery manufacture [42].

Melting lead to make fishing sinkers has also been reported as a source of lead exposure. In Cartagena, Colombia, the parents of all children with BLLs >10 μg/dL worked in and lived near small metal smelting factories with poor indoor air quality, or were fishers who made lead sinkers for their fishing nets. The highest BLLs were in children from a neighborhood near a shoreline where many family incomes were derived from fishing [43]. Similarly, Brown et al. conducted a study in Chuuk, Federated States of Micronesia, and found that 61% of elevated BLLs among children could be attributed to parents who made lead fishing weights [44].

3.4. Paint

The most common source of lead poisoning for the majority of young children in the United States is deteriorated, leaded residential paint and lead-contaminated house dust and soil. Lead was commonly used in residential paint before 1950; in the 1960s the paint industry voluntarily began to limit lead in residential paint. Although regulations limiting lead content in paint for residential use were enacted in the United States in 1978, leaded paint remains in many old homes. A wide distribution of housing built before 1950 exists across the United States (Fig. 2) and poses a potential health threat. The need for ongoing vigilance was highlighted by the death of a 2- year-old Sudanese refugee girl who, on 21 April 2000, became the first child in the United States known to die from lead poisoning in the 10 previous years [45]. The exposure occurred in the United States and was caused by lead paint in the home.

In response to her death, the state where the death occurred revised its testing recommendations to include two tests for immigrants, upon arrival, and 6 months after resettlement, to monitor changes in BLLs. The state found that BLLs for nearly 30% of the refugee children became elevated after resettlement, which suggested that the lead exposure occurred in the United States. Investigations showed that elevated BLLs were associated with living in old homes, the presence of lead hazards, behaviors that increased the chance of ingesting lead, and chronic and acute malnutrition [46]. Malnutrition is common in refugee populations [47]. Anemia is a particular concern for children exposed to lead because iron deficiency can enhance lead absorption and, thus, increase risk for elevated BLLs.

Reports from Portugal, India, and South Africa indicate that children in other countries are also being exposed to residential lead paint. In Portugal’s Oporto Historical Center, a residential area characterized by houses with deteriorating lead paint that were built in the 1900s, children aged 1–5 years were tested for lead poisoning [48]. BLLs ranged from 4.7 μg/dL to 42.5 μg/dL with a mean of 13.9 μg/dL; 85.8% of children had BLLs ≥10 μg/dL. Qualitative lead-paint tests of the walls of the homes were positive for 91% of children with BLLs ≥20 μg/dL and 14% for children with BLLs <10 μg/dL. In India, studies conducted in Mangalore and Karnataka found lead-based paint in the homes of 3 of the 10 children with BLLs of at least 40 μg/dL. These 10 children were part of a blood-lead study of 107 school children who were randomly selected [49]. In Johannesburg, South Africa, lead was found in the paint of 17% of the homes sampled in old and new suburbs that represented a variety of socioeconomic backgrounds. The percentage of lead by weight in some samples reached 29% [50].
et al. conducted a study of lead content in paint samples in India, China and Malaysia and found that 66% of new paint samples contained ≥5000 ppm (0.5%) of lead, the US definition of lead-based paint in existing housing, and 78% contained ≥600 ppm (0.06%), the limit for new paints [51].

3.5. Traditional remedies

Complementary or alternative medicine has become widespread in Western countries. Because the remedies are “natural” they are believed to be free of toxic effects and health risks. However, ethnic remedies may contain lead and other metals and toxic substances. For example, certain branches of ayurvedic medicines contain heavy metals because the metals are thought to have therapeutic benefits for particular ailments. Several cases of lead poisoning from ingesting medicinal products that contain lead in New Zealand [52], Italy [53], and the United States [54] have been reported in recent scientific literature. Traditional remedies that contain lead have been reported to CDC for decades [52–64]. In 2004, three cases of lead poisoning by ayurvedic medicines were reported to CDC. Subsequently, CDC posted an alert on the Epidemic Information Exchange (Epi-X), a web-based communication that allows public health professionals to share preliminary surveillance information. In response to this posting, nine additional adult cases of lead poisoning associated with ayurvedic medicines were reported to CDC [54].

A traditional remedy imported from the Dominican Republic and sold in botanicas (i.e., shops that sell herbs) in the United States was associated with BLLs in two children, twin boys, in Rhode Island [64]. When the boys were identified with elevated BLLs, an investigation for the lead source was conducted promptly because investigators knew their home had been remediated for lead. During the home inspection, litargirio was found in a jar in the boys’ bedroom. Litargirio has been used by Dominicans, particularly those from rural areas, as an antiperspirant/deodorant and as a traditional remedy for burns and fungal infections of the feet. The boys had used the substance as an antiperspirant/deodorant. The litargirio was tested and contained 790,000 ppm (79%) lead. When the children stopped using litargirio, their BLLs decreased [64].

3.6. Electronics

Most electronic devices contain lead and may represent another source of lead when discarded [65]. A study sponsored by the US Environmental Protection Agency (US EPA) reported that electronic items in landfills leached lead at levels exceeding the threshold for hazardous waste. The European Union recognized this potential threat to human health and the environment and acted by banning certain electronic items from landfills. However, the US EPAs most recent estimate is that more than 2 million tons of electronic waste is dumped in US landfills each year. EPA estimates that only about 10% of all obsolete consumer electronics are recycled. The rest are stored somewhere, passed on to second users, or simply tossed in the trash. US recyclers and watchdog groups estimate that 50% of the used US computers, cellphones, and TVs that are sent to recyclers are shipped overseas for recycling in facilities in Taizhou, China, or Lagos, Nigeria, as permitted by federal law. Much of this obsolete equipment ends up as toxic waste with hazardous components exposed, burned, or allowed to degrade in landfills. Waste by-products produced during informal recycling are heavily contaminated with lead.

4. Prevention strategies

The striking aspect of these recent studies and reports is that most lead sources have been reported previously in the scientific literature. Although this article does not represent an exhaustive search of all lead sources reported in the scientific literature, many other sources such as children’s toys, jewelry, and candy are identified and also tend to reappear (Table 1). These sources may appear in new places and poison new populations and all were potentially preventable.

The traditional approach to preventing lead poisoning has been to act after exposure has occurred. The only medical treatment available is chelation, which can save lives in persons with very high BLLs. However, chelating drugs are not always available in developing countries and have limited value in reducing the sequelae of lead poisoning [66,67]. Children aged 12–33 months with referral BLLs ranging from 22 to 44 μg/dL were enrolled in a randomized clinical trial and received either placebo
or succimer. Neuropsychological tests at 3 years after randomization [66] and at age 7 years [67] revealed no developmental benefit in the group that received succimer. These findings highlight the importance of implementing environmental measures to prevent lead exposure. The best protection for all people is to control lead sources on a global scale. We recommend three key strategies to prevent lead poisoning: identify sources, eliminate or control sources, and monitor environmental exposures and hazards.

4.1. Identify sources

Sources of lead may be historic contamination, recycling old lead products, or manufacturing new products. Vast reservoirs of lead remain in our environments and could emerge as health threats. For example, old lead pipes in Washington, DC, did not pose a serious health risk to local residents until a change in water treatment [68] caused the lead to become more available in drinking water. Another potential hazard is lead paint in old homes. In the United States, an estimated 38 million homes contain lead-based paint. Although this represents a substantial reduction from 64 million homes with lead paint in 1990, there are still 24 million that have significant lead hazards [69]. When homes with lead paint deteriorate or are remodeled without taking proper lead-control precautions, the lead can become available in dust and soil and result in human exposure.

Products imported from countries that do not adequately limit the use of lead and enforce those regulations may also contain harmful levels of lead. The United States has issued many recalls of toys and children’s products in 2007 because they have been found to contain lead (Table 2). In 2003, it was determined that a young child with a BLL of 123 µg/dL had swallowed a toy medallion [70].

### Table 1
Examples of published reports of elevated blood lead levels associated with imported products containing lead by exposure source

<table>
<thead>
<tr>
<th>Exposure source</th>
<th>Description/exposure pathway</th>
<th>Year report published</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tamarind candy</td>
<td>Lead leaches from pots and wrappers</td>
<td>1998, 2002</td>
</tr>
<tr>
<td>Ceramic glaze</td>
<td>Lead in ceramic glaze leached into stored beverages</td>
<td>1989, 2004, 2006</td>
</tr>
<tr>
<td>Toy jewelry</td>
<td>Ingestion of a necklace and a metallic charm</td>
<td>2004, 2006</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Product description</th>
<th>Lead source</th>
<th>Units recalled</th>
<th>Date of recall</th>
<th>Country of manufacture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children’s Metal Necklaces</td>
<td>Metals contain lead</td>
<td>2900</td>
<td>2/22/2008</td>
<td>China</td>
</tr>
<tr>
<td>Children’s Memory Testing Cards</td>
<td>Surface paint</td>
<td>5300</td>
<td>2/22/2008</td>
<td>China</td>
</tr>
<tr>
<td>Children’s Table and Chair</td>
<td>Surface paint</td>
<td>50</td>
<td>2/8/2008</td>
<td>China</td>
</tr>
<tr>
<td>Pendants and Candle Charms</td>
<td>Metals contain lead</td>
<td>460,000</td>
<td>2/7/2008</td>
<td>Korea</td>
</tr>
<tr>
<td>Children’s Sketchbooks and Colored Spirals</td>
<td>Paint on spiraled metal bindings</td>
<td>80,000</td>
<td>2/6/2007</td>
<td>China</td>
</tr>
<tr>
<td>Toy Gardening Hand Rakes</td>
<td>Paint on toy</td>
<td>400</td>
<td>2/5/2008</td>
<td>China</td>
</tr>
<tr>
<td>Toy Wooden Block and Train Sets</td>
<td>Surface paint</td>
<td>30,000</td>
<td>12/2/2008</td>
<td>China</td>
</tr>
<tr>
<td>Classroom Reading and Math Aids</td>
<td>Surface paint</td>
<td>185,000</td>
<td>1/31/2008</td>
<td>China</td>
</tr>
<tr>
<td>Educational Assessment Blocks</td>
<td>Surface paint</td>
<td>18,000</td>
<td>1/24/2008</td>
<td>China</td>
</tr>
<tr>
<td>Big Wooden Blocks and Wooden Train Sets</td>
<td>Surface paint</td>
<td>15,000</td>
<td>1/24/2008</td>
<td>China</td>
</tr>
<tr>
<td>Toy Racing Cars</td>
<td>Surface paint</td>
<td>2000</td>
<td>1/23/2008</td>
<td>China</td>
</tr>
<tr>
<td>Cranium Cadoon Board Games</td>
<td>Surface paint</td>
<td>38,000</td>
<td>1/17/2008</td>
<td>China</td>
</tr>
<tr>
<td>Play Mats</td>
<td>Surface paint</td>
<td>60</td>
<td>1/6/2008</td>
<td>Taiwan</td>
</tr>
<tr>
<td>Toy Wrestler Figures</td>
<td>Surface paint</td>
<td>5400</td>
<td>1/15/2008</td>
<td>China</td>
</tr>
<tr>
<td>Toy Wagons</td>
<td>Surface paint</td>
<td>15,000</td>
<td>1/3/2008</td>
<td>China</td>
</tr>
<tr>
<td>Soldier Bear Toys</td>
<td>Surface paint</td>
<td>11,400</td>
<td>12/19/2007</td>
<td>China</td>
</tr>
<tr>
<td>Duck Water Globes</td>
<td>Painted base</td>
<td>60</td>
<td>12/13/2007</td>
<td>China</td>
</tr>
<tr>
<td>Princess Children’s Metal Jewelry</td>
<td>Metal contains lead</td>
<td>1000</td>
<td>12/13/2007</td>
<td>China</td>
</tr>
<tr>
<td>Baby Toy and Speed Racer Cars</td>
<td>Toys contain lead</td>
<td>300,000</td>
<td>12/13/2007</td>
<td>China</td>
</tr>
<tr>
<td>Fishing Games</td>
<td>Parts contain lead</td>
<td>14,000</td>
<td>12/12/2007</td>
<td>China</td>
</tr>
<tr>
<td>Children’s Sunglasses</td>
<td>Surface paint</td>
<td>260,000</td>
<td>12/7/2007</td>
<td>China</td>
</tr>
<tr>
<td>Pottery Seats</td>
<td>Decorative plaque in back of seat</td>
<td>160,000</td>
<td>12/6/2007</td>
<td>China</td>
</tr>
<tr>
<td>Mini Racing Helmets</td>
<td>Surface paints</td>
<td>1400</td>
<td>12/5/2007</td>
<td>China</td>
</tr>
<tr>
<td>Children’s Metal Necklaces and Bracelets</td>
<td>Jewelry contains lead</td>
<td>10,400</td>
<td>11/21/2007</td>
<td>China</td>
</tr>
<tr>
<td>Assorted Metal Jewelry</td>
<td>Jewelry contains lead</td>
<td>205,000</td>
<td>11/21/2007</td>
<td>China</td>
</tr>
<tr>
<td>Children’s Necklace and Earring Sets</td>
<td>Jewelry contains lead</td>
<td>4500</td>
<td>11/21/2007</td>
<td>China</td>
</tr>
<tr>
<td>Children’s Metal Jewelry</td>
<td>Jewelry contains lead</td>
<td>43,000</td>
<td>11/21/2007</td>
<td>China</td>
</tr>
<tr>
<td>Children’s Pencil Pouches</td>
<td>Paint of pouch zipper pulls</td>
<td>84,200</td>
<td>11/21/2007</td>
<td>China</td>
</tr>
<tr>
<td>Curious George Dolls</td>
<td>Surface paint and hat</td>
<td>175,000</td>
<td>11/8/2007</td>
<td>China</td>
</tr>
<tr>
<td>Toy Robot</td>
<td>Surface paint</td>
<td>25000</td>
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<td>1300</td>
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<td>Surface paints</td>
<td>3600</td>
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<td>7200</td>
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<td>Dragster and Funny Car</td>
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<td>75,000</td>
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<td>Galaxy Warriors Toy Figures</td>
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<td>10/31/2007</td>
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The medallion was removed from his abdomen, tested, and found to contain 38.8% lead. It had been purchased in a US vending machine and a recall was issued for 150 million of the necklaces. The child survived, however, the recall did not adequately protect all children.

In 2006, a child aged 4 years died of acute lead poisoning [71]. This was the first child lead-poisoning death since 2000 in the United States. The autopsy revealed a heart-shaped metallic charm in the abdomen that was found to have a lead content of 99.1%. The charms were recalled; this was the 15th recall of leaded toys in the United States. The autopsy revealed a heart-shaped metallic charm in the abdomen that was found to have a lead content of 99.1%. The charms were recalled; this was the 15th recall of leaded toys in the United States. The autopsy revealed a heart-shaped metallic charm in the abdomen that was found to have a lead content of 99.1%. The charms were recalled; this was the 15th recall of leaded toys in the United States. The autopsy revealed a heart-shaped metallic charm in the abdomen that was found to have a lead content of 99.1%. The charms were recalled; this was the 15th recall of leaded toys in the United States. The autopsy revealed a heart-shaped metallic charm in the abdomen that was found to have a lead content of 99.1%. The charms were recalled; this was the 15th recall of leaded toys in the United States. The autopsy revealed a heart-shaped metallic charm in the abdomen that was found to have a lead content of 99.1%. The charms were recalled; this was the 15th recall of leaded toys in the United States. The autopsy revealed a heart-shaped metallic charm in the abdomen that was found to have a lead content of 99.1%. The charms were recalled; this was the 15th recall of leaded toys in the United States. The autopsy revealed a heart-shaped metallic charm in the abdomen that was found to have a lead content of 99.1%. The charms were recalled; this was the 15th recall of leaded toys in the United States.
2 years. In 2007, a series of recalls of children’s toys that were suspected of containing lead was issued in the United States. Other products that children can access also have been recalled over several decades.

4.2. Eliminate or control sources

Controlling potential sources of lead requires targeted and often multiple approaches. These should include developing, implementing, and enforcing effective lead-control policies to reduce lead emissions, clean contaminated sites, offer incentives to encourage safer practices, and restrict nonessential uses of lead. In many cases, effective technology exists to reduce lead emissions. For example, there are technological solutions that can reduce dangerous lead emissions from smelting facilities [72–76]. Soil remediation can lower lead concentrations [77–79] that remain long after lead-smelting emissions are reduced. Without reduction of air emissions and remediation of soil, home hygiene and clean neighborhood campaigns are of little value in decreasing elevated BLLs.

The importance of regulations in lead-control efforts to prevent re-emergence of known hazardous products is illustrated by the availability of leaded house paint in countries without existing laws [51]. A study that sampled house paint from four Asian countries and tested their lead content found that some brands of paint sold in China, India and Malaysia had high lead content. In contrast those same brands marketed in countries such as Singapore that had regulatory limits on lead in house paint either had markedly lower or no detectable levels of lead [51].

Implementation and enforcement of safe worksite practices is another lead-control strategy. Ye and Wong reviewed lead studies reported in the Chinese scientific literature from 1990 to 2005 [80]. The authors compared workplace lead concentrations and the prevalence of lead poisoning among workers before and after passage of the 2002 Occupational Diseases Prevention Act that included provisions for regulatory enforcement. Lead concentrations in both lead-battery and lead-smelter industries far exceeded the occupational exposure limits for lead before and after passage of the law. After passage of the law, the prevalence of lead poisoning decreased significantly in lead-battery factories (45.5% vs. 36.8%) and slightly in lead smelters (33.8% vs. 31.4%). However, the high prevalence of lead poisoning among workers indicates the need for stronger control measures and enforcement. Safe worksite practices are also important to protect the workers’ family members from exposure to contaminated work clothes [81,82].

The impact of enforcing strong laws for the remediation of homes in which a child with an elevated BLL had been identified was assessed. The assessment compared the number of properties that had multiple children with elevated BLLs in two US states in 1992–1993 with the number of these same properties that had children with elevated BLLs 5 years later [83]. Both states had well-established, lead poisoning-prevention programs with nearly universal testing of children and widespread public education. Both states had laws to remediate a home if a child with an elevated BLL was identified. The addresses of houses where a child with a BLL $\geq 25$ μg/dL lived between 1992 and 1993 were identified. A 5-year follow-up ascertained BLLs of children who subsequently lived at those addresses. There was a fourfold increased chance of a subsequent child tenant being identified with a BLL $\geq 10$ μg/dL for a house in the state with limited laws and enforcement compared with a house in the state with strict laws and enforcement.

Another lead-control strategy is to develop practices that promote the use of commercially available and technically well-
understood, safer alternatives to lead. The successful reduction in leaded gasoline use in many developing countries is attributed in part to the World Bank’s practice of requiring that countries include strategies to replace leaded gasoline with unleaded gasoline in their development plans. The World Bank supports governments in adopting appropriate policies and developing strategies, facilitating policies, and implementing lead phase-out strategies [31].

These efforts have contributed to widespread phase-out of leaded gasoline (Fig. 3). A similar approach could be adopted to control unregulated battery smelting by offering buy-back programs and ‘cradle to cradle’ registration of lead–zinc batteries that allows tracking them from manufacture, though use, recycling and re-marketing.

4.3. Monitor environmental exposures and hazards

Testing children’s BLLs has been a key prevention strategy for decades. Results of blood-lead testing can be used to identify populations at high risk and define risk factors for elevated BLLs, which can be used to target interventions. However, not all countries have the resources to conduct population-based lead-poisoning surveillance. Targeted and episodic lead testing of populations that may be at risk for lead poisoning can be a cost-effective way to identify and monitor population exposures [42].

Case management of individuals with elevated BLLs has involved identifying and removing lead sources after exposure has occurred. Ideally, we should monitor lead hazards to protect people before they are exposed. Lead levels in air are monitored in many countries to ensure that the public’s health is protected. Businesses involving lead should routinely test their workers to monitor BLLs. More can be done to track recycling of batteries and electronic goods to ensure that emissions are properly contained to protect families from exposure to lead and prevent contamination of the environment. Testing of imported products that children may use should be increased and tracked. The manufacture of products, such as leaded paint and traditional medicines, in countries without strong lead-control laws and enforcement can result in exposing people in many countries. Often, these exposures are identified after a person with lead poisoning has been diagnosed. Mobile electronic health communication systems such as text message alerts can alert public health practitioners to emerging threats. These systems disseminate information quickly across large geographic areas and highlight issues that could be missed by routine surveillance systems.

5. Conclusion

Even in countries where lead control has been vigilant, vast reservoirs of lead still exist in soil, dust, and house paint; these sources will continue to contribute to the population lead burden for many years to come. In addition, lead is stored in bone, therefore, it can result in adverse health outcomes in adults many years after exposure. Further, maternal bone lead can be mobilized during pregnancy and serve as an endogenous source of lead exposure to the developing fetus [20]. In recognizing that there is no safe BLL for children and that chelating agents have limited value in reducing the sequelae of lead poisoning, all nations should control or eliminate lead hazards in children’s environments before they are exposed. Primary prevention, i.e., preventing people from being exposed to lead is the only solution.

References


