

Childhood

Lead Poisoning



**World Health
Organization**

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WHO Library Cataloguing-in-Publication Data

Childhood lead poisoning.

1.Lead poisoning - etiology. 2.Lead poisoning - prevention and control. 3.Child. 4.Infant. 5.Environmental exposure. 6.Public health practice. I.World Health Organization.

ISBN 978 92 4 150033 3

(NLM classification: QV 292)

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Printed by the WHO Document Production Services, Geneva, Switzerland.

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Abbreviations

Organizations and other entities

ASTM	American Society for Testing and Materials
CDC	United States Centers for Disease Control and Prevention
CPSC	United States Consumer Product Safety Commission
EPA	United States Environmental Protection Agency
HUD	United States Department of Housing and Urban Development
JECFA	United Nations Food and Agriculture Organization and World Health Organization Joint Expert Committee on Food Additives
OAS	Organization of American States
OECD	Organisation for Economic Co-operation and Development
UNEP	United Nations Environment Programme
USPSTF	United States Preventive Services Task Force
WHO	World Health Organization

Technical terms

BLL	blood lead level
DALYs	disability-adjusted life years
EBLL	elevated blood lead level
IQ	intelligence quotient
PM ₁₀	particulate matter less than 10 µm in diameter

Preface

Although many countries have initiated programmes to lower the level of lead in the environment, human exposure to lead remains of concern to health care providers and public health officials worldwide. For over 35 years the World Health Organization and the International Programme on Chemical Safety have been concerned about the adverse effects on health of lead in the environment. The evaluation of human health risks arising from foodborne lead has been carried out by the World Health Organization on four occasions since 1972. In addition, health-based guidance values for lead in water, air and the workplace have been developed by various task groups convened by the World Health Organization. *Environmental Health Criteria 3: Lead*, published in 1977, examined the effects of lead on human health, and *Environmental Health Criteria 85: Lead – Environmental Aspects* was published in 1989. During the past 10 years, a large body of knowledge on the effects of lead on neurobehavioural development of children at low levels of exposure has accumulated.

This booklet focuses on what is known about childhood lead poisoning, an entirely preventable disease.

Foreword

Dear Colleagues,

It is with great pleasure I present to you this booklet on Childhood Lead Poisoning.

Lead poisoning has been a scourge to human health for millennia. Childhood lead poisoning has been a recognized clinical entity since the first decade of the 20th century. Lead has had devastating consequences for the health of the world's children. At high levels of acute exposure, lead attacks the brain and central nervous system to cause coma, convulsions and even death. Children who survive acute lead poisoning are typically left with grossly obvious mental retardation and behavioural disruption. At lower levels of exposure that cause no obvious symptoms and that previously were considered safe, lead is now known to produce a spectrum of injury that causes loss of cognition, shortening of attention span, alteration of behaviour, dyslexia, attention deficit disorder, hypertension, renal impairment, immunotoxicity and toxicity to the reproductive organs. For the most part, these effects are permanent. They are irreversible and untreatable by modern medicine. When lead exposure is widespread – as happened in the 20th century when leaded petrol and lead-based paints were extensively disseminated in the environment – the health and well-being of entire societies are compromised. And when this happened, the economic costs in terms of medical care and diminished opportunity amounted worldwide to hundreds of billions of dollars a year. Prevention is the best way to deal with lead poisoning.

This booklet synthesizes the wisdom of hundreds of peer-reviewed publications and scores of World Health Organization documents. It is intended to be accessible and practical for health workers in all countries. I commend it to you.

Maria Neira, Director

Public Health and Environment
World Health Organization

Summary

This booklet describes childhood lead poisoning, one of the most common and best understood childhood diseases of toxic environmental origin. Acute and chronic lead poisoning remain problems of enormous importance for child health and development worldwide. Lead has no essential role in the human body, and lead poisoning accounts for about 0.6% of the global burden of disease. Lead poisoning is entirely preventable.

The major sources of children's exposure to lead are:

- lead added to petrol
- lead from an active industry, such as mining (especially in soils)
- lead-based paints and pigments
- lead solder in food cans
- ceramic glazes
- drinking-water systems with lead solder and lead pipes
- lead in products, such as herbal and traditional medicines, folk remedies, cosmetics and toys
- lead released by incineration of lead-containing waste
- lead in electronic waste (e-waste)
- lead in the food chain, via contaminated soil
- lead contamination as a legacy of historical contamination from former industrial sites.

Intense, high-dose exposure to lead causes acute symptomatic poisoning, characterized by colic, anaemia, and depression of the central nervous system that may result in coma, convulsions and death. Acute, symptomatic lead poisoning still occurs today and is most commonly detected among children in low-income countries and marginalized populations or in children living in lead-polluted sites.

Blood lead levels that were considered previously to be *safe* are now understood to compromise health and injure multiple organs, even in the absence of overt symptoms. The most critical consequence of low level lead toxicity in utero and during childhood is damage to the developing

brain and nervous system. The immune, reproductive and cardiovascular systems are also adversely affected by relatively low levels of exposure to lead – that is, less than 10 µg/dl.

The consequences of brain injury from exposure to lead in early life are loss of intelligence, shortening of attention span and disruption of behaviour. Because the human brain has little capacity for repair, these effects are untreatable and irreversible. They cause diminution in brain function and reduction in achievement that last throughout life.

Recent research indicates that lead is associated with neurobehavioural damage at blood levels of 5 µg/dl and even lower. There appears to be no threshold level below which lead causes no injury to the developing human brain. The Joint FAO/WHO Expert Committee on Food Additives re-evaluated lead in June, 2010 and withdrew the provisional tolerable weekly intake guideline value on the grounds that it was inadequate to protect against IQ loss.

The neurobehavioural toxicity caused by lead places great economic burdens on families and societies. When exposure to lead is widespread, low level toxicity can damage health, reduce intelligence, damage economies, and incapacitate the future leadership and security of entire countries. An economic analysis conducted in the United States found the current costs of childhood lead poisoning to be US\$ 43 billion per year. A recent cost–benefit analysis undertaken in the United States found that for every US\$ 1 spent to reduce lead hazards, there is a benefit of US\$ 17–220. This cost–benefit ratio is better than that for vaccines, which have long been described as the single most cost-beneficial medical or public health intervention.

The goal of this booklet is to inform and educate health professionals – paediatricians, other clinicians, nurses, and public health officials at all levels – about the importance of childhood exposure to lead and lead poisoning and its serious consequences.

This booklet emphasizes that the contexts, sources and routes of exposure to lead differ for children in different communities, countries and regions around the world, although the biology of childhood lead poisoning is the same globally.

Introduction: lead poisoning – a persistent problem

Lead poisoning is one of the most common and best-recognized childhood diseases of toxic environmental origin. Children around the world today are at risk of exposure to lead from multiple sources. Lead poisoning accounts for about 0.6% of the global burden of disease (WHO, 2009).

Patterns and sources of exposure to lead, prevalence rates of lead poisoning and the severity of outcomes vary greatly from country to country and from place to place within countries. Countries also vary greatly in their degree of recognition of the problem and in the strength and effectiveness of their lead poisoning prevention programmes. Some countries have robust programmes for monitoring levels of lead in blood and the environment, as well as strong programmes for primary and secondary prevention of childhood lead poisoning. These countries have imposed bans on certain uses of lead, have set environmental standards and have deployed screening programmes. Some countries have lead *hot spots*, such as battery recycling plants, smelters, refineries, mines, hazardous waste sites and sites where waste is burned in the open.

Some countries recognize that they have a childhood lead-poisoning problem in relation to certain exposure sources, but have not yet implemented assessment and exposure prevention programmes. And in countries where the potential problem of lead poisoning has not yet been recognized, there are no screening or surveillance programmes and, as a result, public health authorities have little or no knowledge of the existence of a childhood lead-poisoning problem. Because of this heterogeneous situation, the true picture of global and regional lead poisoning in children is not yet fully defined. The contribution of lead poisoning to the global burden of disease and its effect on the global economy and human development are probably still underestimated.

Numerous international conferences and declarations have recognized the importance of childhood lead poisoning and the need to intervene to prevent it (see Annex for examples). The 1989 Convention of the Rights of the Child and the 1992 Agenda 21 adopted by the United Nations Conference on Environment and Development both addressed the need to protect children from toxic chemicals. The 1997 Declaration of the Environment Leaders of the Eight on Children's Environmental Health

acknowledged the importance of lead poisoning as a major environmental hazard and called for action to reduce children's blood lead levels and to fulfil the Organisation for Economic Co-operation and Development Declaration on Lead Risk Reduction. The 2002 Bangkok Statement on Children's Health and the Environment called for the removal of lead from gasoline (Suk, 2002). In 2005, the Health and Environment Ministers of the Americas agreed in the Declaration of Mar del Plata to "strengthen sub-regional and national actions to achieve a complete elimination of lead in gasoline and its reduction from other sources" (OAS, 2005). The 2006 Declaration of Brescia on Prevention of the Neurotoxicity of Metals recommended: the immediate elimination of tetra-ethyl lead from the gasoline supplies of all nations; the review of all uses of lead, including recycling, in all nations; and urgent reduction of current exposure standards (Landrigan et al., 2007). The 2009 Busan Pledge for Action on Children's Health and Environment further affirmed the commitment of the global community to end childhood lead poisoning.

This booklet has its origins in the meeting of the Informal Working Group on Lead Exposure in Children convened by the World Health Organization (WHO) and hosted by the German Network for Children's Health and the Environment at the Ludwig Maximilians University of Munich, Munich, Germany, on 30 November and 1 December 2006. Scientists, clinicians, and public health professionals from low-, middle- and high-income countries presented scientific evidence at this meeting on their experiences in researching the toxicity of lead.

The nature, sources and routes of exposure to lead

What is lead?

Lead is a heavy metal with a bluish-grey colour. It has a low melting point, is easily moulded and shaped, and can be combined with other metals to form alloys (see Box 1 for more facts about lead). For these reasons, lead has been used by humans for millennia and is widespread today in products as diverse as: pipes; storage batteries; pigments and paints; glazes; vinyl products; weights, shot and ammunition; cable covers; and radiation shielding.

Box 1. Facts about lead

Elemental lead. The chemical symbol for lead is Pb (from the Latin name for lead, plumbum). Lead has an atomic number of 82 and an atomic weight of 207.2. It is a bluish-grey metal that tarnishes easily in air to a dark grey. The density of lead is 11.34 g/cm³. It has a low melting point of 327.46 °C or 621.43 °F.

Naturally occurring ores. Lead ores comprise 0.002% (15g/t) of the earth's crust. They include galena (lead sulfide), anglesite (lead sulfate), cerussite (lead carbonate), mimetite (lead chloroarsenate) and pyromorphite (lead chlorophosphate).

Inorganic lead. This is the form of lead found in old paint, soil, dust and various consumer products. The colour varies, depending on the chemical form, and the most common forms are white lead (a lead carbonate compound), yellow lead (lead chromate, lead monoxide) or red lead (lead tetraoxide). Lead acetate has a sweetish taste.

Organic lead. Tetra-ethyl lead is the form of lead used in leaded gasoline. Organic forms of lead are extremely dangerous, as they are absorbed through the skin and are highly toxic to the brain and central nervous system, much more so than inorganic lead. The combustion of organic lead – when it is added to petrol as a fuel additive – results in the release of lead into the atmosphere.

All forms of lead are toxic!

Tetra-ethyl lead was used extensively from the 1930s to the 1970s as a petrol additive to improve engine performance (Rosner & Markowitz, 1985; Landrigan, 2002). Tetra-ethyl lead has been eliminated from the petrol supplies of the majority of countries, but is still used in about 9 countries (UNEP, 2010).

Lead used by industry comes from mined ores (primary) or from recycled scrap metal or batteries (secondary). Today, most of the lead in global commerce is secondary and is obtained from recycling lead-acid batteries. Most (97%) of the world's batteries are reported to be recycled, mostly in low-income countries and mostly in informal, largely uncontrolled settings.

Global consumption of lead is increasing today, because of increasing demand for energy-efficient vehicles. The largest current use of lead is in storage batteries for cars and other vehicles. This use now exceeds the use of lead in petrol (International Lead and Zinc Study Group, 2009). There are many lead-related cottage (home-based) industries, including repairs of electrical appliances using lead solder, small family painting businesses and backyard car repairs). Sometimes these harmful activities are the only means of livelihood for poor families and communities.

Prior to human exploitation people were not exposed to lead

Lead constitutes 0.002% of the Earth's crust, and in nature it exists mainly as lead sulphide. Lead has become widely distributed in the biosphere only in the past few thousand years, almost entirely as the result of human activity (National Research Council, 1972). Once lead is introduced into the environment, it persists.

This trend of increasing environmental lead levels is illustrated by geochemical data that show the accumulation of lead in the Greenland ice cap over the past three millennia (Murozumi, Chow & Patterson, 1969). By far, the greatest increase occurred in the 20th century, due mostly to the burning of tetra-ethyl lead in automotive engines and the subsequent distribution of lead in the atmosphere.

In a similar fashion, measurements of the amount of airborne lead deposited in Scottish and Canadian peat bogs showed that background pre-industrial deposition amounted to only about 0.01 mg lead m⁻² a⁻¹. In the 1990s, however, this rate of deposition had increased to 8 mg lead m⁻² a⁻¹, even after lead was eliminated from gasoline in many of the surrounding areas (Kylander, Weiss & Kober, 2009).

Investigations of human skeletal remains indicate that the body lead burden of today's populations is 500–1000 times greater than that of their

pre-industrial counterparts. The pre-industrial blood lead level in people is estimated to have been about 0.016 µg/dl. In remote regions of the southern and northern hemispheres in the late 1980s, blood lead levels were reported to be 0.78 µg/dl and 3.20 µg/dl, respectively (Flegal & Smith, 1992).

By far the largest contributor to global environmental lead contamination has been the use of lead in petrol (OECD, 1999; Landrigan, 2002). World lead consumption rose steadily between 1965 and 1990, when it reached about 5.6 million tonnes. Between 1980 and 1990, the consumption of lead in high- and middle-income countries increased only slightly, whereas for the same years in low-income countries it increased from 315 000 tonnes to 844 000 tonnes per year. Global lead contamination – resulting from human activities and attributable to the greatly increased circulation of lead in soil, water and air – remains significant.

With continued efforts to remove lead from petrol, paint and pigments, solder and other well-known sources, blood lead levels worldwide are expected to continue their decline. However, hot spots from smelting, mining, and metal recycling operations – some of them ongoing and others the legacy of the past – remain significant problems. And despite a century of accumulated evidence about its danger to the health of children, lead continues too often to be added to paints, pigments, toys, traditional medications, cosmetics and other consumer products, especially as manufacturing shifts to low-income countries that lack environmental and product content controls and policies.

Environmental sources of lead

Lead absorption pathways

An exposure pathway must, by definition, have five components: (a) a source of contamination (such as deteriorating lead-based paint on the walls, doors and windows of a home; used car batteries; open burning of waste); (b) an environmental medium and transport mechanism (such as lead contaminated dust on the floor of a home, lead smoke from open burning, or lead exhaust from leaded gasoline); (c) a point of exposure (such as children's hands, the floor, or children's toys); (d) a route of exposure (such as eating the dust through hand-to-mouth behaviour); and (e) an exposed population (such as children in the home environment or pregnant women in polluted environments or workplaces). When all

five components are present, the exposure pathway is termed a complete exposure pathway.

Ingestion is the most common route of exposure to lead for children. Once lead has been swallowed, it enters a child's body by absorption from the gastrointestinal tract. Children's innate curiosity and their age-appropriate hand-to-mouth behaviour result in their bringing lead-containing or lead-coated objects, such as contaminated soil or dust, to their mouth, and thus greatly increase their risk of exposure. This route of exposure is magnified in children who engage in pica. The amount of soil and house dust that a typical 1–6-year-old child ingests is said to be 100 mg/24 h, but a more conservative estimate of 200 mg/24 h with an upper percentile of 400 mg/24 h has also been suggested. Children in the United States who engage in pica may ingest as much as 10 g/24 h (EPA, 2002). These values are important when setting standards for remediation that will not result in elevated blood lead levels.

Inhalation of airborne lead may not typically be a major source of exposure for children, in contrast to occupationally exposed adults, because the particle size of airborne lead in community environments is usually too large to be inhaled. Inhalation can occur, however, when children are exposed to lead in particulate matter less than 10 µm in diameter (PM₁₀) from car exhausts (in countries that still use leaded gasoline) and smoke from the open burning of waste. Attention should also be paid to the possibility of inhalation exposure from other unusual circumstances in children's environments, such as heat-gun stripping of painted surfaces, welding and torch cutting of lead painted steel or steel alloys containing lead, or burning lead contaminated materials (such as old car batteries) in and near children's homes. In these situations, very fine particles of airborne lead are generated and can be inhaled by children. Severe cases of paediatric lead poisoning have been documented (Amitai et al., 1987, 1991).

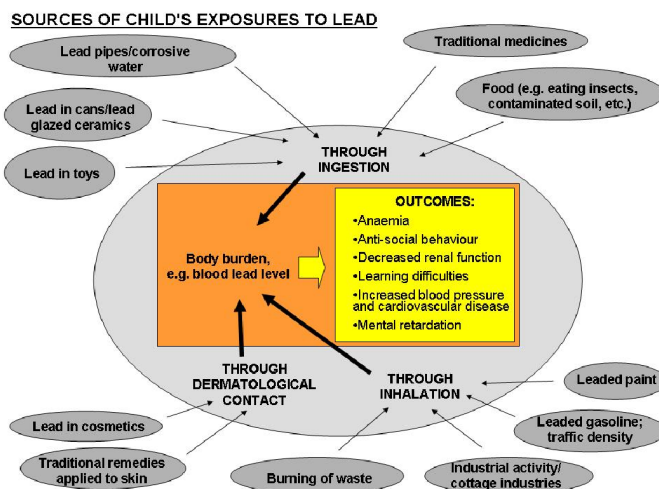
The most common sources of lead in children's environments today

Worldwide, the following sources and products account for most cases of childhood exposure to lead and lead poisoning:

- lead added to gasoline
- lead from an active industry, such as mining (especially in soils)
- lead-based paints and pigments,
- lead solder in food cans
- ceramic glazes
- drinking-water systems with lead solder and lead pipes
- lead in products, such as herbal and traditional medicines, folk remedies, cosmetics and toys
- lead released by incineration of lead-containing waste
- lead in electronic waste (e-waste)
- lead in the food chain, via contaminated soil
- lead contamination as a legacy of historical contamination from former industrial sites.

Fig. 1 describes some of the routes by which lead moves from its primary source to reach the bodies of children.

Fig. 1. Sources of children's exposure to lead



The relative importance of these various potential sources of exposure to lead varies both within and between countries and regions. In the United States, for example, lead-based paint is an important source of exposure, while in Mexico, lead-glazed ceramics used for food storage and preparation are much more important (Rojas-López et al., 1994). In the low-income world the informal recovery of lead from car batteries and the open burning of waste are very important sources of environmental lead contamination.

Socioeconomic factors are important predictors of exposure to lead. Poor families are more likely to live near industrial plants that handle lead, such as battery recyclers or smelters. Also, they are more likely to dwell on polluted lands, to work in polluting industries, or to live in older housing with lead-based paint. Finally, poor children are more likely to have iron or calcium deficient diets, and as a result they may absorb lead more efficiently.

Culture and ethnicity are strongly related to such risk factors for exposure to lead as the use of traditional cosmetics, herbal medicine products and pica during pregnancy. These exposures are, however, not limited to their countries of origin, as global migration and global markets increase and as the popularity of complementary and alternative medicine grows in middle- and high-income societies.

Lead toxicity and its effects on health

The toxic nature of lead has been known since at least 2000 BC. Lead poisoning was common in Roman times, due to the use of lead in water pipes, earthenware containers and wine storage vessels, and the use of a leaded syrup, called *sapa*, to sweeten wine (Eisinger, 1982). Lead poisoning associated with occupational exposure was first reported in 370 BC. In 1767, the American statesman and philosopher Benjamin Franklin obtained a list of patients in La Charité Hospital in Paris who had been admitted because of symptoms which, although not recognized as such, were evidently those of lead poisoning. All the patients were engaged in occupations that exposed them to lead (Franklin, 1786). In 1839, the French physician, Tanquerel des Planches described the symptoms of acute lead poisoning on the basis of 1213 admissions to La Charité Hospital between 1830 and 1838. His study was so thorough that little has subsequently been added to the clinical picture of the symptoms and signs of acute lead poisoning in adults (Tanquerel des Planches, 1839). Lead poisoning became

common among industrial workers in the 19th and early 20th centuries, when workers were exposed to lead while engaged in trades involving smelting, painting, plumbing, printing and many other industrial activities (Thackrah, 1832). In 1882, following the deaths of several employees in the lead industry in the United Kingdom, a parliamentary enquiry was initiated into working conditions in lead factories. This resulted in passage of the 1883 Factory and Workshop Act, which required lead factories in the United Kingdom to conform to certain minimum standards, such as the provision of ventilation and protective clothing.

Lead toxicity in children

Lead poisoning was first recognized as a paediatric disease in Australia over 100 years ago. A series of 10 cases in Queensland was reported in 1892; 12 years later, after extensive investigation, the source was found to be peeling, lead-based, residential paint on the verandas of the children's homes (Gibson, 1904).

Children are now understood to be at particularly high risk of lead toxicity. From conception onward, children have a greater risk of exposure and greater susceptibility to the toxic effects of lead than do adults. There exist windows of vulnerability to lead in early life – during embryonic, fetal and early postnatal life – that have no counterparts in adult life (American Academy of Pediatrics Committee on Environmental Health, 2003).

Children are at increased risk of exposure to lead because they:

- are exposed to lead throughout pregnancy.
- eat more food, drink more water and breathe more air per unit of body weight (American Academy of Pediatrics Committee on Environmental Health, 2003);
- have an innate curiosity to explore their worlds and engage in developmentally appropriate hand-to-mouth behaviour and sometimes also in pica, an abnormal extreme form of hand-to-mouth behaviour;
- spend more time in a single environment, such as the home;
- are more likely to have nutritional deficiencies that lead to increased absorption of lead (Mahaffey, 1995);

- have more years of future life and thus a longer time to develop delayed consequences of early exposures, potentially even including dementia that may arise as a delayed consequence of early exposure to lead (American Academy of Pediatrics Committee on Environmental Health, 2003); and
- lack control over the circumstances of their environment.

From conception onward – that is, throughout pregnancy – lead that has accumulated in a woman’s bones is removed from her bones and passes freely from mother to child; maternal and fetal blood lead levels are virtually identical. Once in the fetal circulation, lead readily enters the developing brain through the immature blood–brain barrier.

Children’s biological susceptibility to lead is greater than that of adults because of the following.

- The developing human brain undergoes rapid growth, development and differentiation, and lead can interfere with these extraordinarily complex and delicate processes. The sequelae of brain damage caused by chronic, low-level exposure to lead are irreversible and untreatable (Needleman et al., 1990; Bellinger, Stiles & Needleman, 1992; Rogan et al., 2001). This great vulnerability extends from prenatal life into infancy and early childhood.
- Exposure to lead early in life can *re-programme* genes, which can lead to altered gene expression and an associated increased risk of disease later in life (Basha et al., 2005; Wu et al., 2008; Pilsner et al., 2009). Early exposure to lead can also reduce an individual’s capacity to successfully weather other neurological insults later in life (Schneider & DeCamp, 2007).
- Gastrointestinal absorption of lead is enhanced in childhood – up to 50% of ingested lead is absorbed by children, as compared with 10% in adults.
- Relatively low levels of exposure to lead that may not have any immunotoxic effects on a mature organism can, if experienced during the critical period of immune system development, result in immune dysfunction later in life. The adverse effect may be latent and may not emerge until the immune system is stressed at a point in time well removed from the exposure. There is a threefold to twelvefold

difference in reported in vivo lowest-observed-adverse-effect levels between perinatal and adult exposure periods for various lead-induced immunotoxic effects (Dietert & Piepenbrink, 2006).

Health effects of lead poisoning in children

Lead is associated with a wide range of toxicity in children across a very broad band of exposures, down to the lowest blood lead concentrations yet studied, both in animals and people. These toxic effects extend from acute, clinically obvious, symptomatic poisoning at high levels of exposure down to subclinical (but still very damaging) effects at lower levels. Lead poisoning can affect virtually every organ system in the body. The principal organs affected are the central and peripheral nervous system and the cardiovascular, gastrointestinal, renal, endocrine, immune and haematological systems.

Acute clinical toxicity

Intense, acute, high-dose exposure to lead can cause symptomatic poisoning in children. It is characterized by colic, constipation, fatigue, anaemia and neurological features that can vary from poor concentration to stupor. In the most severe cases, a potentially fatal acute encephalopathy with ataxia, coma and convulsions can occur. In many instances, children who survive acute lead poisoning go on to have permanent and clinically apparent deficits in their neurodevelopmental function (Byers & Lord, 1943).

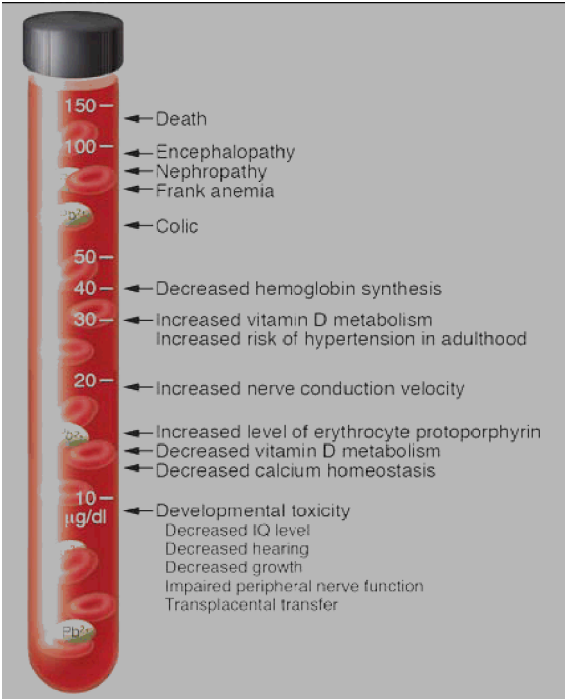
Overt clinical signs and symptoms of lead poisoning are still common today in many low-income countries and in children living around active lead-polluted sites or legacy hot spots. In contrast, these signs and symptoms are less common in countries and places where screening for lead and environmental monitoring are routinely performed. However, health professionals and public health agencies everywhere should be aware of the signs and symptoms of acute lead poisoning, to ensure prompt diagnosis of individual cases and recognition of clusters of cases that may be related to a new or previously unrecognized lead source in an exposed community.

Subclinical toxicity

The term *subclinical toxicity* denotes the concept that relatively low-dose exposure to lead at blood lead levels previously thought to be *safe* can cause

harmful effects not evident in a standard clinical examination. Although they are not clinically obvious, the subclinical toxic effects of lead can be very damaging. The premise underlying the concept of subclinical toxicity is that there is a dose-related continuum of toxic effects in which clinically apparent effects have their asymptomatic (but still very real) counterparts (Landrigan, 1989) (Fig. 2).

Figure legend: Fig. 2. Paediatric effects of lead at various blood lead levels



Source: Adapted from Bellinger & Bellinger (2006).

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Haematological toxicity

Anaemia is the classic clinical manifestation of lead toxicity in erythrocytes. The severity and prevalence of lead-induced anaemia correlate directly with the blood lead concentration. Younger and iron deficient children are at higher risk of lead-induced clinical anaemia. The anaemia induced by lead is caused primarily by impairment of heme biosynthesis, but an

increased rate of erythrocyte destruction may also occur (Schwartz et al., 1990).

Neurological toxicity

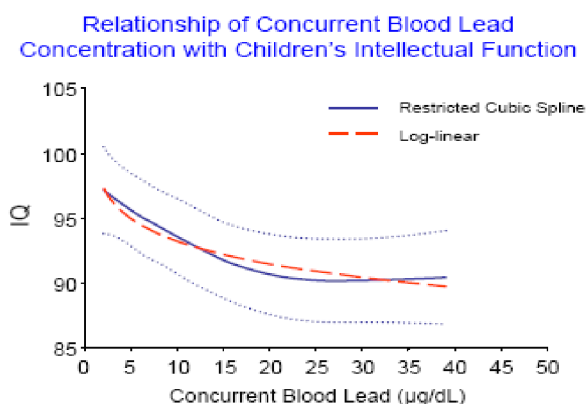
In the peripheral nervous system, the motor axons are the principal target of lead toxicity. Lead-induced pathological changes in these fibres include segmental demyelination and axonal degeneration. Extensor muscle palsy with wrist and ankle drop has been recognized since the time of Hippocrates as the classic clinical sign of the peripheral neurological toxicity of lead; however, this generally only occurs with chronic lead poisoning and is rare in acute exposure to lead.

In the central nervous system, lead causes asymptomatic impairment of neurobehavioural function in children at doses insufficient to produce clinical encephalopathy. Early cross-sectional studies of the association between lead and intelligence quotient (IQ) were conducted in the 1970s (Landrigan et al., 1975b; Needleman et al., 1979). These studies showed that clinically asymptomatic children with elevated body lead burdens had a four- to five-point deficit in mean verbal IQ scores compared with children from the same communities with lower lead burdens. (It is notable that the *lower* lead burdens of the referent groups included in these studies were quite elevated by today's standards, sometimes in excess of 30 µg/dl.) This finding was still strongly evident after correcting for a wide range of socioeconomic, behavioural and biological factors. Similar results were reported in other early studies. Today, on the basis of multiple studies in several countries, it is estimated that about a quarter to a half of an IQ point is lost for each 1 µg/dl increase in the blood lead level during the preschool years for children who have blood lead levels in the range of 10–20 µg/dl (Schwartz, 1994; Pocock, Smith & Baghurst, 1994).

In young children, whole blood lead levels as low as 1–3 µg/dl are associated with subclinical neurobehavioural toxicity (Canfield et al., 2003). The largest of these studies examining this issue – based on an analysis of data from more than 4800 children 6–16 years of age who participated in the Third National Health and Nutrition Examination Survey in the United States – found an inverse relationship between blood lead and math and reading scores in children at blood lead concentrations lower than 5 µg/dl. The relationship was still evident after adjustment for an extensive series of potential confounding factors. Indeed, the dose–response relationship between blood lead levels and loss of IQ was stronger at blood lead levels

lower than 10 $\mu\text{g}/\text{dl}$ than at higher levels (Lanphear et al., 2000). An international pooled analysis of data from seven cohorts has confirmed these findings (Lanphear et al., 2005) (see Fig. 3). An increase in blood lead level from less than 1 $\mu\text{g}/\text{dl}$ to 10 $\mu\text{g}/\text{dl}$ was associated with a six IQ point decrement, which is considerably greater than the decrement associated with an increase in blood lead level from 10 $\mu\text{g}/\text{dl}$ to 20 $\mu\text{g}/\text{dl}$. The findings of this pooled analysis – that there are adverse effects below 10 $\mu\text{g}/\text{dl}$ and that the effects are steepest at the lowest levels of exposure – have been confirmed by numerous investigators (Emory et al., 1999, 2003; Bellinger & Needleman, 2003; Wasserman et al., 2003; Chiodo, Jacobson & Jacobson, 2004; Despres et al., 2005; Fraser, Muckle & Despres, 2006; Hu et al., 2006; Kordas et al., 2006; Schnaas et al., 2006; Tellez-Rojo et al., 2006; Chiodo et al., 2007; Surkan et al., 2007).

Fig. 3. Relationship between concurrent blood lead level and children's IQ



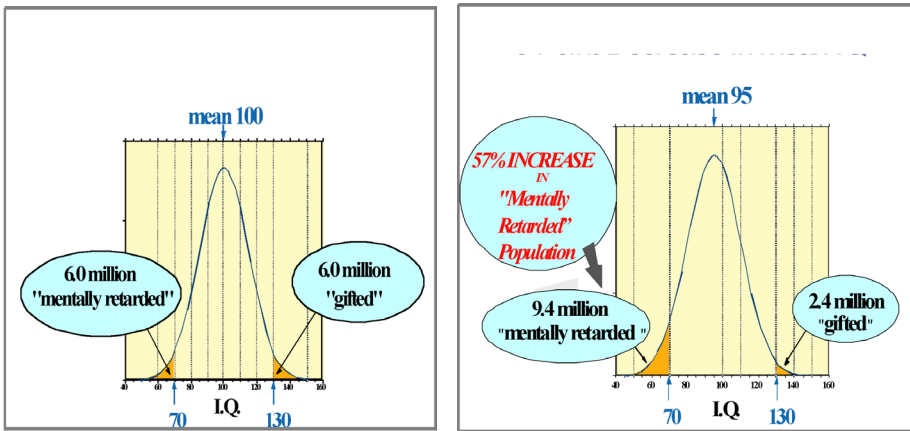
Source: Lanphear et al. (2005).

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When a population's exposure to lead is sufficiently widespread to cause a decrease in its mean IQ, there results a substantial increase in the number of children with diminished intelligence and mental retardation. At the same time, there is a substantial reduction in the number of children with truly superior intelligence (see Fig. 4). The consequences are: (a) a substantial increase in the number of children who do poorly in school, who may require special education and other remedial programmes, and who may not contribute fully to society when they become adults;

(b) a reduction in a country's future leadership; and (c) a widening gap in socioeconomic attainment between countries with high and low levels of population exposed to lead (Needleman et al., 1979).

Fig. 4. Losses associated with a five-point drop in IQ in 100 million people



Source: Colborn, Dumanoski & Myers (1996).

Prenatal exposure to lead and exposure to lead in human milk

From conception onward, lead that has been stored in the mother's skeleton in years past is released into the circulation under the metabolic stress of pregnancy. Throughout pregnancy, lead readily crosses from the maternal to the infant circulation, and the blood lead concentration of the infant becomes virtually identical to that of the mother (Markowitz, 2000). Once in the infant, lead can penetrate the immature blood–brain barrier to enter the developing brain (Lidsky & Schneider, 2003). The developing human brain is particularly susceptible to lead, even at very low levels of exposure.

The source of lead in an infant's blood seems to be a mixture of about two thirds dietary and one third skeletal lead, as shown by studies that exploited the differences in lead isotopes stored in the bones of women migrating from Europe to Australia (Gulson et al., 2003). Although lead appears in human milk, the concentration is closer to that of plasma lead and much lower than that found in whole blood, so little is transferred to the infant.

Because infant formulas and other foods for infants also contain lead (as may the water used to prepare these foods), women with commonly encountered blood lead concentrations who breastfeed their infants expose them to slightly less lead than if they do not breastfeed. In Mexico, giving women supplemental calcium during lactation resulted in a small (less than 2 µg/dl) decrease in the mother's blood lead concentration, presumably by decreasing skeletal resorption (Ettinger et al., 2006). Theoretically, this could further diminish the transfer of lead through breast milk.

Mechanisms of lead neurotoxicity

One of the mechanisms underlying the neurotoxicity of lead lies in its ability to substitute for other polyvalent cations (particularly divalent cations, such as calcium (Ca^{2+}) and zinc (Zn^{2+})) in the molecular machinery of living organisms (Godwin, 2001). In most instances, the characteristics of lead allow it to bind with greater affinity than calcium and zinc ions to protein binding sites. These interactions allow lead to affect different biologically significant processes, including metal transport, energy metabolism, apoptosis, ionic conduction, cell adhesion, intercellular and intracellular signalling, diverse enzymatic processes, protein maturation, and genetic regulation. Membrane ionic channels and signalling molecules seem to be one of the most relevant molecular targets that contribute to lead's neurotoxicity; the developing central nervous system is particularly susceptible (Markowitz, 2000).

Irreversibility of lead neurotoxicity

The neurobehavioural changes associated with early exposure to lead appear to be persistent and irreversible (Needleman et al., 1990; Burns et al., 1999; Dietrich et al., 2001; Cecil, 2008; Wright et al., 2008). These changes are not reversed or improved by chelation therapy (Rogan et al., 2001). There is an inverse relationship between early childhood exposure to lead and performance on tests of cognitive function and behaviour 10, 15 and 20 years after the blood lead levels were measured (Bellinger, Stiles & Needleman, 1992). Early exposures have also been linked to increased rates of hyperactivity, inattentiveness, failure to graduate from high school, conduct disorder, juvenile delinquency, drug use and incarceration (National Research Council, 1992; Sciarillo, Alexander & Farrell, 1992; Needleman et al., 1990, 1996, 2002; Dietrich et al., 2001; Nigg & Casey, 2005; Braun et al., 2006, 2008; Fergusson, Boden & Horwood, 2008; Nigg

et al., 2008; Wang et al., 2008; Wright, 2008; Ha et al., 2009). Also, it has been observed in the United States that the murder rate fell sharply after the removal of lead from gasoline with a 20 year lag (Nevin, 2007) (Fig. 5), a finding consistent with the notion that exposure to lead in early life is a powerful determinant of behaviour decades later in adult life. Animal studies provide experimental evidence that supports the association between lead and aggression (Li et al., 2003).

Fig. 5. Correlation between mean blood lead levels and murder rate, United States, 1878–2006



Source: Nevin, 2000.

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It is now quite clear that there are adverse neurodevelopmental effects at the lowest blood lead concentrations yet studied. On the basis of this evidence, it is possible today to affirm that low concentrations of lead are harmful to brain development and cognitive function. A threshold for adverse effects of lead at the population level, however, has not been identified (Schwartz, 1994; Schneider, Huang & Vemuri, 2003; Lanphear et al., 2005).

Lead and renal toxicity

In kidneys, lead causes proximal tubular injury with a characteristic pathology of proximal tubule nuclear inclusion bodies that progress to tubulo-interstitial disease and fibrosis. Lead accumulation in the proximal tubule leads to hyperuricaemia and gout – presumably by inhibiting uric acid secretion – and also to diminished renal clearance, tubular reabsorption and glomerular filtration rate (Gonick, 2008).

Blood lead concentrations greater than 40 µg/dl are associated with an increased risk of nephropathy and related renal failure. Lower levels of exposure to lead can act as a cofactor that increases the risk of renal dysfunction and the rate of functional decline. An inverse relationship between blood lead and glomerular filtration rate has been reported, after adjusting for confounding variables, in most environmental cohort studies; and this relationship has been observed in cohorts with mean blood lead concentrations as low as 2 µg/dl (Akesson et al., 2005). Also, people with diabetes and hypertension are at increased risk of clinical renal dysfunction at lower exposures to lead.

Lead and cardiovascular disease

Among occupationally exposed workers, long-term, high-dose exposure to lead was reported, early in the 20th century, to be associated with an increased incidence of hypertension and stroke (cerebrovascular accident). More recently, several epidemiological studies have found evidence that increased lead absorption, even at relatively low levels, is also associated with significant elevation in blood pressure across general populations with no occupational exposure to lead, such as the population of the United States assessed through the National Health and Nutrition Examination Survey. A recent systematic review concluded that a modest positive relationship between exposure to lead and blood pressure has been identified in numerous studies in different settings, and that some of these studies have identified a dose–response relationship. This review concluded that the association between lead and hypertension is causal.

The hypertensive effects of lead have been confirmed in experimental animal models. Beyond hypertension, studies in general populations have identified a positive relationship between exposure to lead and clinical cardiovascular events (mortality due to cardiovascular disease, coronary heart disease and stroke; and peripheral arterial disease), but the number of studies examining these effects is relatively small. In some studies, these relationships were observed at blood lead levels lower than 5 µg/dl (Navas-Acien et al., 2007). The cardiovascular events associated with exposure to lead add considerably to the total economic costs of lead poisoning in the adult population (Pirkle et al., 1985; Cheng et al., 2001).

Lead and immune and reproductive function

The immune system (Lutz et al., 1999; Bunn et al., 2001; Karmaus et al., 2005) and reproductive system (Selevan et al., 2003; Wu, Buck & Mendola, 2003; Iavicoli et al., 2006) are also adversely effected by relatively low levels of exposure to lead – that is, lower than 10 µg/dl.

Policy implications of lead toxicity at low levels

A recurrent theme in research on childhood lead poisoning over the past 40 years has been that lead is toxic to the developing nervous system at levels previously thought to be safe (Needleman, 2009). In the 1960s, an elevated paediatric lead level was defined by the United States Department of Health and Human Services Centers for Disease Control and Prevention (CDC) as a concentration in whole blood of 60 µg/dl. Then, beginning in the 1970s, recognition grew that lead could cause subclinical neurotoxicity and reduce children's intelligence and alter behaviour at blood lead levels lower than 60 µg/dl. Continued exploration using still stronger study designs and sharper analytical tools has continued to show that lead is toxic to children at still lower levels.

In response to these data, the CDC in the United States has repeatedly reduced the level of lead in blood that defines childhood lead poisoning. Thus, in the 1970s, the level was reduced to 40 µg/dl, and then to 30 µg/dl. In the 1980s, it was reduced to 25 µg/dl. Most recently, in the early 1990s, the CDC reduced the blood lead level of concern to 10 µg/dl, the level that remains to this day.

In light of the growing amount of evidence on neurodevelopmental and other systemic effects of lead at levels below 10 µg/dl, some researchers have suggested that the current level of 10 µg/dl may not be adequately protective of child health (Lanphear et al., 2000; Canfield et al., 2003; Bellinger & Needleman, 2003; Wasserman et al., 2003; Lanphear et al., 2005; Hu et al., 2006; Kordas et al., 2006; Schnaas et al., 2006; Tellez-Roj et al., 2006; Surkan et al., 2007). Some jurisdictions in the United States (e.g., the California Environmental Protection Agency and the New York City Department of Health) have translated more recent evidence on low-level lead toxicity into policy. A number of public health agencies are considering or have already taken action to recognize that any level of exposure to lead is associated with harm to the developing child, and

scientists have suggested that a lower blood lead level – perhaps 2 µg/dl – should be the trigger for follow-up and assessment of a child by health professionals (Gilbert & Weiss, 2006). The Joint FAO/WHO Expert Committee on Food Additives re-evaluated lead in June, 2010 and withdrew the provisional tolerable weekly intake guideline value on the grounds that it was inadequate to protect against IQ loss (JECFA, 2010).

Exposure to lead and the global burden of disease

In 2000, WHO assessed the global burden of disease due to a number of *risk factors* (Prüss-Ustün, 2004). Environmental exposure to lead was among these. Fig. 6 shows the estimated disability-adjusted life years (DALYs) for mild mental retardation and cardiovascular disease in 2000.

DALYs are the metric used by WHO to assess the global burden of disease. DALYs are defined as the sum of years of life lost due to death and to disability due to a particular disease or condition. Each condition is associated with a defined severity weight.

Blood lead levels vary widely from country to country and region to region. The highest blood lead levels and the largest burden of disease from exposures to lead are seen in low-income countries – in particular, in areas where there are industrial uses of lead (such as smelters, mines and refineries) and/or where leaded gasoline is still used heavily. When revised estimates of the burden of disease were made in 2004, 16% of all children worldwide were estimated to have levels above 10 µg/dl (WHO, 2009). Of children with elevated levels, an estimated 90% live in low-income regions.

Fig. 6. DALYs due to lead-induced mild mental retardation and cardiovascular diseases, in 2000

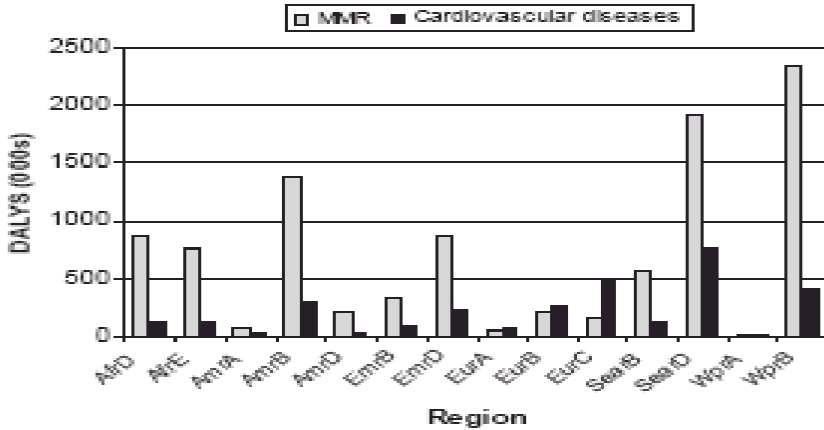


Fig. 3. DALYs due to lead-induced mild mental retardation (MMR) and cardiovascular diseases in the year 2000.

Note. The following abbreviations, by WHO subregion, are used in this figure: AfrD = Africa D; AfrE = Africa E; AmrA = America A; AmrB = America B; AmrD = America D; EmrB = Eastern Mediterranean B; EmrD = Mediterranean D; EurA = Europe A; EurB = Europe B; EurC = Europe C; Sea 1B = South-East Asia B; Sea 1D = South-East Asia B; WprA = Western Pacific A; WprB = Western Pacific B.

Source: Adapted from Prüss-Ustün et al. (2004).

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The total burden of disease attributable to lead amounts to about 9 million DALYs. This represents about 0.6% of the global burden of disease (WHO, 2009). Since these estimates were published, considerable evidence has accumulated indicating that these figures underestimate the burden of disease and costs attributable to low-level lead toxicity.

Economic costs of lead poisoning

The economic costs associated with childhood exposure to lead are substantial (Landrigan et al., 2002). The economic benefits of successful interventions against lead poisoning have also been shown to be enormous (Grosse et al., 2002; Gould, 2009). These benefits far outweigh the costs of creating a national programme for screening, surveillance and prevention of lead poisoning.

The costs of childhood lead poisoning may be divided into *direct* and *indirect* costs. The direct or medical costs include those costs associated with the provision of medical care to children with acute lead poisoning. These costs may be substantial in an individual case, but in most countries they do not comprise a major fraction of the total economic costs of lead poisoning, because acute lead poisoning is relatively rare today in most countries. The direct costs of lead poisoning also include the costs of treating cardiovascular disease in adults who have developed hypertension following exposure to lead.

The indirect or nonmedical costs of childhood lead poisoning describe the economic burden it places on society. Analyses of the indirect costs of lead poisoning have focused mainly on the loss of intelligence that is caused by lead and on the lifelong decrements in economic productivity that result from this loss of intelligence. These costs are sometimes referred to as *lost opportunity costs*. Using a conservative estimate, the decrease in intelligence attributable to each 1 µg/dl increase in blood lead level is 0.25 IQ points, and the decrement in lifetime economic productivity associated with each lost IQ point is 2.4%. When exposure to lead is widespread in a society, the aggregate loss of intelligence (and thus of economic productivity) can be substantial (Salkever, 1995). Benefits that have yet to be monetized relate to the decrease in crime rates associated with the reduction of lead levels in blood subsequent to the phasing-out of leaded petrol.

An analysis of the direct medical and indirect societal costs associated with lead poisoning in children in the United States found these costs to amount to US\$ 43 billion annually, even at the current relatively low levels of exposure to lead in the United States (Landrigan et al., 2002). The additional indirect costs due possibly to increased need for special educational services, institutionalization or incarceration of people who suffered lead poisoning in childhood were not included in this computation, because of lack of good data on the frequency of those events.

Interventions to prevent lead poisoning have demonstrated very large economic benefits. Grosse et al. have estimated that the increases in children's intelligence, and thus in lifetime economic productivity, that resulted from removal of lead from petrol have produced a benefit of between US\$ 110 billion and US\$ 319 billion in each birth cohort in the United States (Grosse et al., 2002).

A recent cost–benefit analysis suggests that for every US\$ 1 spent to reduce lead hazards, there would be a benefit of US\$17–220. This cost–benefit ratio is better than that for vaccines, which have long been described as the single most cost-beneficial medical or public health intervention (Gould, 2009).

Exposure to lead and environmental injustice

Although lead can affect children from every socioeconomic stratum, socially and economically deprived children and children in low-income countries carry the greatest burden of disease due to lead. Poor people are more likely to be exposed to lead and to be at risk of exposure to multiple sources. They are more likely to dwell on marginal land (near landfills and polluted sites), to live in substandard housing with ageing and deteriorating lead-based paint, and to live near industry, sites where waste is burned and heavy traffic. Also, lead smelting is used by marginalized populations to generate resources.

Evidence from observational and experimental studies show that the physiological and psychological effects of stress can modify the adverse neurological and cardiovascular effects of exposure to lead – that is, an equivalent level of exposure causes greater injury in stressed subjects (Cory-Slechta, 2005; Gump et al., 2005, 2009; Virgolini et al., 2005, 2006; Peters et al., 2007; Surkan et al., 2008). There is also evidence that an enriched environment can mitigate the adverse neurological effects of lead (Schneider et al., 2001; Guilarte et al., 2003).

Communities that lack political influence, communities that are disenfranchised, and ethnic minority groups have repeatedly been shown to be at greater risk of exposure to lead than other populations. Such communities typically lack the power to force companies, such as lead recyclers or smelters, to stop polluting their environment (American Academy of Pediatrics Committee on Environmental Health, 2003).

Exploitive child labour is a further source of exposure to lead for the poorest children. In some regions of the low-income world, children may be used as inexpensive labour in industries with a high risk of exposure to dangerous chemicals. Also, some children may be compelled to work in highly polluted environments where administrative and engineering controls are non-existent and proper hygiene is neglected.

The unfinished success story of leaded gasoline

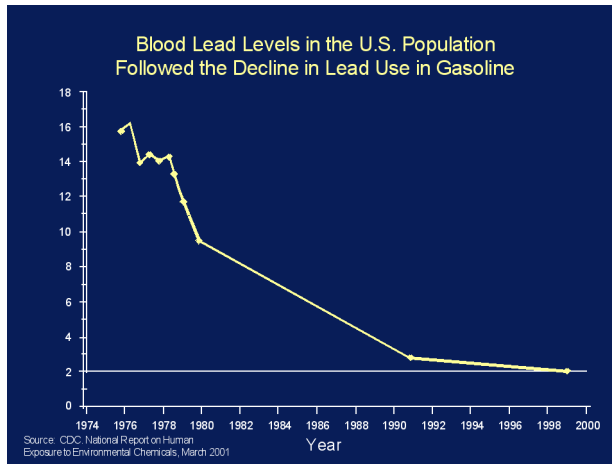
The phasing-out of lead from petrol is regarded as a critical first step in reducing the concentration of lead in blood worldwide and is considered a major international public health achievement (Falk, 2003). Unfortunately 9 countries, mostly low income, have not phased out leaded petrol (UNEP, 2009b) (see Table). This action alone is one of the most effective ways of reducing the general population's exposure to lead. Shifting from the production of leaded to unleaded petrol is technically simple. Modern refineries do not need to make extensive investments; however, old refineries operate at a loss and should be either modernized or closed down. Phasing out leaded petrol is a prerequisite for additional air-pollution control measures, such as the use of unleaded petrol for catalytic converters, which reduce emissions of nitrogen oxides and other harmful air pollutants.

Results from countries that span the spectrum of economic diversity have been astonishing. This story represents a model of what can be done to combat lead poisoning through a combination of robust surveillance and strong governmental action. This story illustrates the key point that *childhood lead poisoning* is nearly *100% preventable*.

In the United States, the phasing-out of leaded petrol between 1976 and 1995 was associated with a more than 90% reduction in mean blood lead concentration (Annest et al., 1983; CDC, 1997b; Jones et al., 2009) (see Fig. 7). The percentage of children in the United States aged 1–5 years with blood lead levels greater than or equal to 10 µg/dl declined from 77.8% in the late 1970s to 4.4% in the early 1990s, and the average lead level of a child in the United States declined to 1.9 µg/dl between 1999 and 2002 (CDC, 2005a). At the same time, lead was eliminated from solder used in food cans and new residential paint products (President's Task Force on Environmental Health Risks and Safety Risks to Children, 2000). An estimated gain of 5–6 points in mean population IQ score was associated with the decline in mean blood lead concentrations, and this

gain in IQ has been calculated to yield an annual economic benefit of between US\$ 100 billion and US\$ 300 billion (Grosse et al., 2002).

Fig. 7. Blood lead levels in the United States and the decline of lead use in gasoline, 1974–2000



Source: Adapted from CDC (2005b).
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Similar effects were recorded in western Europe, Australia, Canada, New Zealand and South Africa (von Schirnding & Fuggle, 1996; Landrigan, 2002). In a number of rapidly industrializing countries, too, including China, El Salvador, India, Mexico and Thailand, declines in blood lead levels have followed the removal of lead from petrol (OECD, 1999; Mathee et al., 2006; He, Wang & Zhang, 2009). Worldwide, unleaded petrol now accounts for an estimated 99% of total sales. This means that about 200 million people are exposed to leaded petrol (UNEP, 2009b). By late 2010, almost all countries have phased out leaded petrol, leaving 9 countries with leaded petrol. Three countries are using only leaded petrol, and 6 countries are using both leaded and unleaded petrol (see Table).

Table. Countries that have not yet eliminated leaded petrol

Country	Comment
Afghanistan	
Algeria	Dual. Announced will phase out in 2013
Bosnia-Herzegovina	Expected phase-out date 2011
Iraq	Dual
Montenegro	Dual. Announced will phase out January 2011
Myanmar	
North Korea	Fully leaded
Serbia	Dual
Yemen	Dual

Use of lead in paint

After lead in petrol, lead in paint is one of the largest sources of exposure to lead. Leaded paint can remain a source of exposure to lead and lead poisoning for many years after the paint has been applied to surfaces. For example, even though the use of lead in paint was essentially banned in the United States in 1978, there are still 38 million housing units that have lead in paint (CPSC, 1977).

Childhood lead poisoning from residential lead-based paint was first described in 1892 in Brisbane, Australia, and the first published warnings of the risk to children from lead in residential paint were published more than a century ago (Gibson, 1904). Lead was eventually banned from house paint in Australia in 1914, the same year that childhood lead poisoning was first reported in America. However, it was not until 1978 that the United States followed suit; by that time, 74% of dwellings in the United States contained some lead-based paint. Lead-based paint was the dominant form of house paint in low-income countries for many decades, and a significant percentage of homes still contain it on some surfaces.

As lead-based residential paint deteriorates with age or as homes undergo renovation, lead-containing dust is generated. As a result, lead can be found in lead-painted homes in high concentrations in three media to which children may be directly or indirectly exposed: (a) the paint itself; (b) interior dust; and (c) exterior soil or dust. As of 2009, lead-based residential paint was the main source of lead poisoning in children in the United States. Efforts to reduce children's blood lead levels by intensive home and school cleanings and encapsulation in the United States provide a temporary reduction of exposure where the work was properly

undertaken. Ultimately, homes painted with lead-based products require complete remediation of the problem, as discussed in the environmental management section of this booklet. The burden of this cost falls on landlords, government and housing agencies, and private homeowners decades after the implementation of policies to eliminate the use of lead-based residential paint.

In the United States, after the Second World War, the use of lead in paint decreased markedly. In 1978, the United States banned the use of paint containing more than 0.06% (600 parts per million) lead by weight on toys, furniture, and interior and exterior surfaces of houses and other buildings and structures used by the general public. New standards for lead in paint and consumer products in the United States, which came into effect in 2009, require that any product designed or intended primarily for children 12 years of age or younger will be banned if it contains more than 300 parts per million total lead content by weight for any part of the product. Also, these new standards require the lead content for surface paint in furniture, toys and other children's products to be a maximum of 0.009% (90 parts per million) by weight. A similar pattern took place in European countries, too, before the general sale of leaded paint was prohibited in the European Union in 1989.

In Australia, restrictions on the use of lead in paints for domestic application were initiated in the early part of the 20th century. Appendix I of the Australian Standard for the Uniform Scheduling of Drugs and Poisons, known as the Uniform Paint Standard, provides control of paints sold to consumers. For such applications, the supply of paint with a lead concentration greater than 0.1% is prohibited. In 2007, the Australian Paint Manufacturers Federation lobbied the Australian industrial chemicals regulator, the National Industrial Chemicals Notification and Assessment Scheme, to restrict the importation and use of 14 lead compounds still used in paints. In 2008 and 2009, restrictions were placed on the manufacture and import of 14 lead compounds as components of industrial surface coatings and inks at concentrations greater than 0.1%.

Also, South Africa restricted the use of lead in household paints to less than 600 parts per million, beginning in 2009. Although Thailand took action to phase out paint containing lead almost two decades ago, in essentially a voluntary initiative by the paint industry, five of seven brands of paint recently sampled contained levels of lead as high as 30 000 parts per million (UNEP, 2009a).

In many middle- to high-income countries, titanium dioxide is now often used as a substitute for lead in paint. Lead is still found, however, in newly manufactured paint and pigments, especially in paint manufactured and sold today (Clark et al., 2006, 2009). For example, high levels of lead are currently found in paint in old as well as newly constructed dwellings in South Africa (Mathee et al., 2007). A survey of pigmented enamel paint purchased in stores in Johannesburg and Cape Town revealed that 83% of samples were lead-based residential paints. Only 2 of the 25 lead-based residential paint products displayed warnings of the high lead content.

In the Russian Federation, interior paints containing lead are restricted by the legislation adopted in the Union of Soviet Socialist Republics in 1929 and 1984 and later by the Russian Federation in 1991 and 1992. In 1991, the Russian Federation ratified the International Labour Office White Lead (Painting) Convention, 1921 (No. 13). Independent research has shown that paints containing lead, mainly exterior paints, can easily be found on the Russian market.

A recent study in China showed that 50% of new paint samples tested contain lead at levels equal to or exceeding 600 parts per million. Despite a wide range in retail prices, there was no correlation between price and lead content among the 58 paint samples collected.

A similar study of new residential paints being sold in India indicated that 84% of enamel paints have lead levels that exceed 600 parts per million. However, one nationally distributed major brand that was available within the same price range as their competitors appeared to have eliminated the use of lead pigment and other lead additives. This suggests that price should not be a deterrent for paint companies to shift to lead-free alternatives and still remain competitive.

Continued use of lead pigments in paints is creating a public health problem for years to come. Substitutes are readily available, making the global elimination of lead in paint an achievable goal.

High concentrations of lead (up to 145 000 µg/g) have been found in paint removed from widely used children's toys that were purchased from major toy, supermarket and stationery chain stores, as well as from flea and craft markets (Montgomery & Mathee, 2005). Box 2 provides additional details about lead in paint.

Box 2. Lead in paint: a new chapter in an old story

A survey undertaken in Johannesburg, South Africa, to assess the presence of lead-based paint in homes made a surprising discovery. Lead-based residential paint was found in 20% of the homes sampled, in both new and old suburbs, and in suburbs with a variety of different socioeconomic backgrounds. Samples of residential paint were collected from homes in 60 randomly selected suburbs across the city. The results indicate that 17% of all samples collected contained lead-based paint (paint that contains lead levels equal to or greater than 0.5% by weight). The percentage of lead by weight in the samples ranged from 0.01% to 29.00% (Montgomery & Mathee, 2005).

A separate survey of new paint samples from China, India and Malaysia revealed that 66% contained more than 5000 parts per million (0.5%) of lead – the United States definition of lead-based paint in existing housing – and 78% contained 600 parts per million (0.06%) or more, the limit for new paints for household use. In contrast, the comparable levels in a nearby high-income country, Singapore, were 0% and 9%, respectively. In examining lead levels in paints of the same brands purchased in different countries, it was found that some brands had lead-based paints in one of the countries and paints meeting United States limits in another; another had lead-free paint available in all countries where samples were obtained (Clark et al., 2006, 2009).

WHO/UNEP initiative to remove lead from paints globally

The Second Session of the International Conference on Chemicals Management, held in Geneva in May 2009, endorsed a global initiative to promote phasing out the use of lead in paints (UNEP, 2009a). This proposal for an initiative was jointly put forward by Toxics Link, the Intergovernmental Forum on Chemical Safety and the United States Environment Protection Agency (EPA) to remove lead from paint. Another such global alliance has made great progress in phasing out leaded gasoline worldwide. The International Conference on Chemicals Management, which is an intergovernmental body that consists of 162 countries, endorsed a global alliance to promote the phasing out of the lead in paints and invited all stakeholders to become members. WHO and the United Nations Environment Programme (UNEP) within their respective mandates, serve as the Secretariat. The alliance will report back on progress to the Third Session of the International Conference on Chemicals Management, in 2012.

Lead-glazed ceramics

The use of lead-glazes in ceramics is ubiquitous and has been implicated as a frequent source of food contamination. In Mexico, the frequency of use

of traditional, low-temperature, lead-glazed pottery has been associated directly with increased blood lead levels of children (Rojas-López et al., 1994). Older cracked pottery, storage of acidic foods, and cooking in the pottery increases the amount of lead that leaches from the glaze. Children of potters engaged in producing leaded ceramic-ware, a cottage industry in many countries, have much higher blood lead levels than children from families employed otherwise. Case studies from other countries, however, also report the ubiquitous use of lead-glazes.

The preferential use of lead-glazed cooking pots may be due to the distinctive flavour of foods prepared in them. However, travellers purchasing souvenir pieces may unknowingly poison their families.

Box 3 discusses the effects on children living in a community in Ecuador that produces ceramic roof tiles and ceramic objects.

Box 3. A small observational study in Ecuador

About half the families in La Victoria, Ecuador, are involved in producing ceramic roof tiles or ceramic objects. They usually engage in activities related to this industry at small worksites situated next to their homes. The clay used in the ceramics is extracted from the local mountains and then moulded into tiles or artefacts. The items are then glazed with lead salts made from melted batteries. After, the ceramics are fired in furnaces for 24–48 hours, permeating the local air with dust and fumes from both the ceramics and the fuel. No environmental precautions are in place.

Children as young as 6 years of age were observed working in this trade. A small observational study enrolled 12 children to evaluate their lead levels. Ten of these children, aged 6–15 years, gave blood samples, and lead levels ranged from 23 µg/dl to 124 µg/dl, with a mean of 70 µg/dl. Three of the children had worked for less than three months; their blood lead levels were less than 50 µg/dl. All of the children who had worked longer than three months had blood lead levels greater than 60 µg/dl. Also, five of the children had repeated one or more years of school (Ide & Parker; 2005).

Lead from recycled car batteries

The reclamation of lead and lead salts from discarded batteries is common around the world and especially in low-income countries. Battery recycling and smelting operations are often small to mid-sized industrial establishments in the informal sector and have minimal environmental or occupational controls. In some cases, the work is conducted within homes. Because lead battery use is expected to increase in the years ahead, with the growing production of electric and hybrid gasoline–electric automobiles, battery reclamation may also be expected to increase. The following two cases highlight the broad reach of this hazardous practice.

Dominican Republic

In March 1997, blood lead levels were measured in 116 lead-poisoned children from a community near a previously active automobile battery recycling smelter in Haina, near Santo Domingo, Dominican Republic. The mean blood lead level at that time was 71 µg/dl with a minimum of 9 µg/dl and a maximum of 234 µg/dl. The government shut down the recycling plant shortly after the initial report of these findings.

Six months later, blood lead levels were re-evaluated, and the follow-up survey confirmed a severe incidence of elevated blood lead level. The mean blood lead level was 32 µg/dl, with a minimum of 6 µg/dl and a maximum of 130 µg/dl. The frequency distribution of blood lead levels showed that only 9% of the children had a blood lead concentrations less than the 10-µg/dl threshold level, 23% had a level between 10 µg/dl and 19 µg/dl, 40% had between 20 µg/dl and 39 µg/dl, 27% had between 40 µg/dl and 99 µg/dl, and the remainder had a blood lead level greater than 100 µg/dl. Of note is that these findings were significantly greater than the mean blood lead level of 14 µg/dl in a comparison group of 63 children in Barsequillo, 6.4 km away. The frequency distribution of blood lead levels for this comparison group showed the following percentages for the same distribution grouping: less than 10 µg/dl (42%), 10–19 µg/dl (32%), and 20–39 µg/dl (16%); in the remaining 10%, blood lead levels were between 40 µg/dl and 99 µg/dl (Kaul et al., 1999).

Senegal

In a neighbourhood of Dakar, Senegal, 18 children died from an aggressive central nervous system disease between November 2007 and March 2008. Consultants from WHO and local health authorities were called in to investigate the deaths. Cultural prohibitions, however, prevented autopsies of the children. To indirectly gather information on the cause of death, the researchers examined 32 of the children's siblings and 23 of the siblings' mothers along with 18 unrelated local children and 8 unrelated adults. All 81 individuals investigated were found to be poisoned with lead, some of them severely. Blood lead levels in the 50 children examined ranged from 39.8 µg/dl to 613.9 µg/dl. Seventeen children showed severe neurological manifestations of lead toxicity. Homes and soil in surrounding areas were found to be heavily contaminated with lead (indoors: up to 14 000 mg/kg; outdoors: up to 302 000 mg/kg) as a result of informal lead-acid

battery recycling with minimal environmental controls. The investigators concluded that the likely cause of death was encephalopathy, resulting from severe lead poisoning. In addition, findings suggested that other inhabitants of the contaminated area, estimated to be 950 in number, were also likely to be lead poisoned through a combination of inhalation and ingestion of lead-contaminated dust (Häfliger et al., 2009).

Lead in air

With the phase out of leaded gasoline in most countries, the concentrations of lead in the ambient air decreased. However, lead can still enter the air from other sources. The open burning of waste is one of the main sources that introduce lead into the environment in many regions. Lead is present in many household products and in many other components of waste that end up in urban waste or in uncontrolled waste deposits. Frequently, the waste in landfills burns spontaneously or is burned intentionally to reduce the volume and to better identify still valuable items it may contain. In many cases, waste is burned in waste sites to recuperate metals from, for example, cables or e-waste. This type of electric waste and e-waste may also be brought to the scavengers' houses or to their poor neighbourhoods where they are burned to recuperate metals; this work is done by groups of families living in areas that surround these sites. Children and adolescents of the scavengers and poor families who live close the waste sites may participate actively in these activities to recuperate metals, and sometimes children look for lead to smelt and make sinks to sell. Smoke from the open burning of waste may pollute the air and transport lead for long distances, thus reaching communities settled kilometres away from the sources. In some cases, waste may be used as a cheap combustible material to cook or to heat the inside of homes, or around them. Lead is also emitted into the air by incinerators, crematoria, and cement kilns that are old or not well controlled; they pollute the air of entire communities. The WHO air quality guidelines for Europe state that the annual average lead level in air should not exceed $0.5 \mu\text{g}/\text{m}^3$ (WHO, 2000).

Lead in drinking-water systems

Lead plumbing (in Latin, *plumbum* = lead) has contaminated drinking-water for centuries, and lead in water can contribute to elevated blood lead concentrations in children. In Roman times, water pipes themselves were made of lead. Today the principal source of lead in drinking-water

in most locales is lead solder. Lead solder used in the joints of pipes and water mains and as a component of brass fittings can leach into drinking-water, especially when the water has an acidic pH (Beattie et al., 1972). The current WHO standard for the lead content of drinking-water is 10 µg/l (WHO, 2008).

Lead in food

More than 80% of the daily intake of lead is derived from the ingestion of food, dirt and dust. The amount of lead in food plants depends on soil concentrations and is highest around mines and smelters. Cereals can contain high levels of lead. Milk or formula is a significant source of exposure for infants. The use of lead-soldered food and beverage cans may considerably increase the lead content, especially in the case of acidic foods or drinks. Lead also comes to unintentionally contaminate food as the result of contamination with soil or from lead used in machinery to process items – for example, wheels for flour that are coated with lead.

Since alcoholic drinks tend to be acidic, the use of any lead-containing products in their manufacture or distribution will raise lead levels. Also, smoking tobacco increases lead intake.

Provisional tolerable weekly intake: WHO guidance values

The provisional level of the maximum amount of a contaminant to which a person can be exposed per week over a lifetime without an unacceptable risk of adverse effects on health is subject to review when new information becomes available. This level for lead is set by the United Nations Food and Agriculture Organization and the WHO Joint Expert Committee on Food Additives (JECFA). The level was originally set in 1982 for infants and children, based on studies conducted with children. In 1993, JECFA reconfirmed the existing tolerable intake of 25 µg/kg body weight per week for infants and children, and extended it to people in all age groups (JECFA, 1993). JECFA re-evaluated lead in June, 2010 and withdrew the provisional tolerable weekly intake guideline value on the grounds that it was inadequate to protect against IQ loss (JECFA, 2010).

Lead in products

Lead is added intentionally to a variety of consumer products for its perceived therapeutic benefit, for the coloration it imparts to the products,

or for the weight it adds to spices sold by weight. For some cultural or ethnic groups, this is a significant source of exposure to lead (Markowitz et al., 1994). About 80% of India's population relies on traditional systems of health care, such as Ayurveda – which originated in South Asia over 2000 years ago. Because of this reliance, South Asian children may be given herbal medicine products for infant colic, teething, colds, and other health conditions. Also, women may use herbal medicine products for overall well being, fertility, diabetes, and other conditions. Unfortunately, recent case reports of lead poisoning associated with Ayurvedic herbal products raise serious health concerns (Ravi et al., 2008). Reported cases include fatal lead encephalopathy of a 9-month-old infant, severe developmental delay in a 5-year-old child, and congenital paralysis and deafness in a preterm infant.

Topical agents applied around the eyes, such as surma and kohl, which are used in Asian and Arabic countries, may be ingested or absorbed (Al-Saleh et al., 1999); and traditional or so-called folk remedies for gastrointestinal or urological disorders may consist largely of lead. Even imported spices and dried fish may be contaminated.

A 2002 literature review cited 15 case reports and six case series associating heavy metal poisonings with the use of Ayurvedic medicines from India. In 2004, the CDC received reports of 12 adult cases of lead poisoning associated with Ayurvedic medicines or remedies in five states, with blood lead levels greater than 80 µg/dl. Of herbal products manufactured in South Asia and sold in Boston South Asian grocery stores, 19% contained lead (median: 40 parts per million; range: 5–37 000 parts per million). Half of these products were recommended for children. A larger follow-up study of 195 Ayurvedic medicines manufactured in the United States and India and purchased on the Internet showed a 19% prevalence of lead-contaminated herbal products (Saper et al., 2008). A study in Saudi Arabia showed that of 247 herbal remedy tests, 16% contained potentially toxic concentrations of heavy metals (Bogusz, al Tufail & Hassan, 2002).

Toys are another potential source of children's exposure to lead. Lead is a problem in toys for two reasons: (a) the toy may be painted with leaded paint; and (b) the toy itself is made of lead. Several recent episodes have been reported of lead in children's toys, and in the United States in 2008 a large-scale recall of imported, lead-painted children's toys was instituted (Weidenhammer, 2009).

A death was reported in a child who swallowed a lead painted trinket (CDC, 2006b). In another case reported, in 2003, in the United States, a young boy swallowed a toy medallion and had a blood lead level of 123 µg/dl. The medallion, which had been purchased in a vending machine, was removed from his abdomen, tested and found to contain 38.8% lead. Subsequently, a recall was issued for 150 million necklaces. The child survived, but the appearance of subsequent case reports and recalls revealed that the recall did not adequately protect all children. Recalls have been reported in such countries as Australia, the United States and the United Kingdom.

Lead contaminated sites

Point sources of environmental lead contamination – such as lead or zinc mines, lead smelters, and battery recycling plants – can create lead contaminated sites. Soil, water, air, and food can be contaminated and subsequently increase the blood lead levels of local residents (Landrigan et al., 1975a; Vimpani et al., 1985; Musliu et al., 2008). Numerous polluted sites in many different areas of the world are well documented; potentially, many similar polluted sites are as yet unrecognized.

Some of these polluted sites are located around active mines, smelters, foundries and factories. Others are located at the sites of abandoned industrial establishments and are referred to as *legacy* polluted sites (Blacksmith Institute, 2007).

Small scale, unregulated *cottage industries*, such as battery-recycling and ceramic-production operations, can also create lead contaminated sites (Matte et al., 1989, 1991). For such industries, distance from the source is an important predictor of blood lead levels, but this can be influenced by prevailing environmental conditions, such as wind and rain. Among the children around the Torreón smelter in Coahuila, Mexico, 92% had blood lead levels greater than 15 µg/dl (García Vargas et al., 2001).

Occupational and take-home exposures to lead

Workers in industries that use lead can bring home lead-laden dust on their clothes, shoes and vehicles, resulting in contaminated dust in their homes. This transfer of lead from workplace to home has been documented to cause cases of lead poisoning in the spouses and children of lead workers (Baker et al., 1977; Chisolm, 1978). The list of occupations that put workers – and hence their families – at risk of exposure to lead include the

production of ceramic pottery, battery recycling, production of stained glass, automobile radiator repair, construction, metal and electronics recycling, and glass work. Exposure to lead also occurs in the smelting and mining industries and through exposure to fuels and oils.

Excessive levels of lead have been observed in child labourers in occupations where exposure to lead is not suspected traditionally. Children who work as scavengers, street vendors, car repairers and ship dismantlers have been observed to have elevated blood lead levels that could not be accounted for by environmental exposures alone. Children engaged in these activities are the same population that is at risk of nutritional deficiencies, which enhances the adverse effects and increases the absorption of lead.

Pica in pregnancy: a special risk factor

In some cultures, pregnant women traditionally eat soil, ceramic fragments or other nonfood materials. In some instances, these materials can contain high levels of lead. The result is that these pregnant women can develop high blood lead levels. Then, because lead can cross freely from the maternal to the fetal circulation throughout pregnancy, serious prenatal brain damage can result (Shannon, 2003; Erdem et al., 2004). With increasingly widespread global migration, medical practitioners worldwide need to be aware of this potential source of maternal and fetal exposure to lead.

Prevention and control of exposure to lead that results from pica during pregnancy may be achieved through a combination of vigorous education of mothers and prenatal caregivers. It can also be achieved through blood lead screening, surveillance and case management of pregnant women, especially of women from communities at known high risk of exposure to lead (Klitzman et al., 2002).

Lead in electronic waste: an emerging hazard

With the global proliferation of computers, cellular telephones and other electronic equipment –as well as rapid cycles of replacement and obsolescence of these instruments – an enormous amount of electronic waste is now generated each year worldwide. Much of this waste – or electronic material near the end of its useful life – is shipped to low-income countries where large numbers of workers in both the formal and informal sectors are involved in separating lead, mercury and other metals

from the waste for recovery and recycling. In the informal sector, much of the work is performed by children. Elevated levels of lead in dust have been seen in communities engaged in this work, and elevated blood lead levels have been reported in children performing this work (Leung et al., 2008; Zheng et al., 2008).

One such report studied children in the Philippines, where child scavengers worked and lived on Smokey Mountain, a garbage dump that received about a third of Manila's garbage before it closed in the 1990s. The study found that the 20 000 residents were exposed to waste from chemical, hospital, and slaughterhouse sources. Children as young as 5–7 years of age work as scavengers. They begin a two-year apprenticeship and work without any protective equipment or clothing. A 1991 survey of 231 scavengers aged 6–15 years, recorded mean blood lead levels of 28.4 µg/dl (standard deviation = 11.5). Blood lead levels greater than 20 µg/dl were recorded in 68.2% of the boys and 58.2% of the girls. The authors compared these data to blood samples from 25 schoolchildren in metropolitan Manila, who had a mean blood lead level of 11 µg/dl (Ide & Parker, 2005).

Diagnosing lead poisoning

Lead poisoning is primarily a subclinical disease. Encephalopathy is an unlikely presenting finding, and gastrointestinal and common neurological complaints may be vague. However, a common clinical picture is abdominal pain, constipation, anaemia and nonspecific neurological features, such as poor concentration and poor language development. The diagnosis of lead poisoning can be suspected if responses to routine questions are affirmative for possible sources of exposure. Such sources include peeling paint in old housings combined with such behaviour as pica, chewing on surfaces, and placing nonfood items in the mouth. Also, proximity to open burning of waste or recycling of car batteries are other sources of lead poisoning.

The most well-recognized and often-observed symptoms of overt lead poisoning involve the gastrointestinal and central nervous systems. The combination of gastrointestinal symptoms with a history of potential or known exposure to lead sources suggests the diagnosis. The combination of recurrent or intermittent abdominal pain, vomiting and constipation should raise the suspicion of lead poisoning, a syndrome known colloquially as *lead colic*. Gastrointestinal symptoms may be present at BLLs as low as 20 µg/dl; however, they are more common in children with BLLs greater

than or equal to 50 µg/dl. Blood lead concentrations in this range are often associated with such neurological effects as poor concentration and speech and/or language delay.

At levels higher than 100 µg/dl, some children may show evidence of encephalopathy, including neurobehavioural deficits that adversely affect social interactions, a marked change in mental activity, ataxia, seizures and coma. Chronically exposed children may not manifest the expected symptoms, although the likelihood of permanent damage, particularly neurological, still exists. Findings of physical examinations in these cases may include signs of increased intracranial pressure, lead lines in the gums, and focal neurological deficits.

The lack of overt symptoms or clinical findings on physical examination does not preclude the risk of these children having persistent central nervous system damage from their exposure. In any case, where exposure to lead is suspected or uncertain, BLL measurements are ultimately required to make the diagnosis (Markowitz, 2000).

Some experienced clinicians measure the blood lead concentration in children with growth retardation, speech or language dysfunction, anaemia, and attention or behavioural disorders. However, a persistent elevation of blood lead concentration into school age is unusual, even if peak blood lead concentration at 2 years of age was high. This is probably because hand-to-mouth activity decreases and the children's body mass increases. Thus, a low blood lead concentration in a school-aged child does not rule out earlier lead poisoning. If the question of current lead poisoning arises, however, the only reliable way to make a diagnosis is with a blood lead measurement. Hair lead concentration gives no useful information and should not be performed. Radiograph fluorescence measurement of lead in bone is available in a few research centres and has been used in children as young as 11 years with acceptable validity for research, but it has no clinical utility as yet (American Academy of Pediatrics Committee on Environmental Health, 2005). Box 4, which follows, summarizes the clinical presentation of lead poisoning.

This box outlines the key elements of the clinical presentation of lead poisoning: symptoms, physical examination and laboratory tests.

Box 4. Clinical presentation of lead poisoning

- Symptoms^a
 - Gastrointestinal
 - Anorexia, nausea, vomiting, abdominal pain, constipation, metallic taste
 - Central nervous system
 - Poor concentration, headache, fatigue, malaise
 - Language and speech delay, behavioural problems
 - Encephalopathy: ataxia, seizure, coma
 - Musculoskeletal
 - Muscle and joint pain (chronic)
 - Other chronic effects
 - Short stature, weight loss, weakness

- Physical examination
 - Signs of intercranial pressure, lead lines in teeth, gout
 - Hypertension

- Laboratory
 - Elevated BLL
 - Haematology
 - Hypochromic anaemia, red blood cells with basophilic stippling, elevated protoporphyrin levels (erythropoietic protoporphyria (EPP) or zinc protoporphyrin (ZPP))^b
 - Hepatic injury
 - Elevated transaminase levels (acute poisoning)
 - Other
 - Hyperuricaemia, hypocalcaemia
 - Urine
 - Proteinuria, glucosuria and aminoaciduria (acute poisoning)
 - Radiological
 - Lead lines in the metaphyses of long bones (chronic poisoning).

^aSymptoms may be absent in spite of significant poisoning.

^bProtoporphyrin levels (EPP or ZPP) are usually not elevated until the BLL is greater than or equal to 25 µg/dl and may also be elevated in other conditions, such as iron deficiency anaemia.

The Environmental History

When obtaining the environmental history of a child, an appropriate combination of the following questions and actions should be included.

- What is the age and general condition of the residence or other structure (school) in which the child spends time?
- Is there evidence of chewed or peeling paint on woodwork, furniture or toys?
- How long has the family lived in that residence?
- Have there been recent renovations or repairs to the house or building?
- Are the windows new?
- Are there other sites at which the child spends significant amounts of time?
- What is the condition or composition of indoor play areas?
- Do outdoor play areas contain bare soil that may be contaminated?
- How does the family attempt to control dust and dirt?
- Does smoke or dust come from external sources close to the building?
- Are there any point sources near the home, such as smelters, metallurgic industries, battery recycling activity (even inactive) or open burning of waste?
- What was the previous use of the land before the building was constructed?
- To what degree does the child exhibit hand-to-mouth activity?
- Does the child exhibit pica?
- Are the child's hands washed before meals and snacks?
- Has anyone in the household ever had lead poisoning?
- What are the occupations of adult household members?
- Are the clothes and shoes used for working activities brought into the house or washed with the home laundry?

- Is the family or any member of the family involved in scavenger activities?
- Is there any work done with lead – for example, car battery recycling, radiator repairs or recuperation of metals – in or around the home?
- What are the hobbies of household members? For example, do they include fishing and preparing weights, working with ceramics or stained glass, hunting and preparing shots for guns, or handicraft activities that use tin or lead solders?
- Are painted materials or waste materials burned in household fireplaces or used as combustibles?
- Are there any local idiosyncratic sources or uses of lead?
- Does the child receive or have access to imported food, food of unsecure origin, cosmetics or folk remedies?
- Is food prepared or stored in glazed pottery or metal vessels?
- Does the family use foods stored in soldered cans?

If the answers to the risk factor questions indicate a risk of exposure to lead, measurement of a BLL should be considered. In addition to identifying children with elevated BLLs, the questions have educational value. The questions stimulate dialogue between the health provider and the parent or caretaker, which opens up an opportunity to educate families about lead hazards.

Clinical indicators for blood lead testing

Clinical indicators for testing BLL include: the suspected or identified presence of a risk factor for exposure, physical signs or symptoms, or the presence of a household member with known exposure to lead. Most individuals with measurable lead exposure are asymptomatic. When symptoms or physical findings of lead poisoning are present, they are often difficult to differentiate, as they are generally nonspecific and quite common. These symptoms include constipation, abdominal pain, anaemia, headache, fatigue, myalgia and arthralgia, anorexia, sleep disturbance and difficulty concentrating. Measurement of BLLs should be considered when these symptoms are present and the suspicion of a source of lead poisoning exists. Measurement of BLLs should also be considered in the work-up of acutely ill children that present with severe colic, seizure or

coma and should be considered in the differential diagnosis of consistent constitutional symptoms (such as persistent headache, myalgia and fatigue) and anaemia.

Conclusion

During the past century, much has been learned about the adverse effects of lead on children. At high levels of acute exposure, lead attacks the brain and central nervous system to cause coma, convulsions and even death. Children who survive acute lead poisoning are typically left with grossly obvious mental retardation and behavioural disruption. At lower levels of exposure that cause no obvious symptoms and that previously were considered safe, lead is now known to produce a spectrum of injury that causes loss of cognition, shortening of attention span, alteration of behaviour, dyslexia, attention deficit disorder, hypertension, renal impairment, immunotoxicity and toxicity to the reproductive organs. For the most part, these effects are permanent. They are irreversible and untreatable by modern medicine. When lead exposure is widespread – as happened in the 20th century when leaded gasoline and lead-based paints were extensively disseminated in the environment – the health and well-being of entire societies are compromised. And when this happened, the economic costs in terms of medical care and diminished opportunity amounted worldwide to hundreds of billions of dollars a year. Prevention is the best way to deal with lead poisoning.

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Annex. Additional information

Existing documents and recommendations

The International Programme on Chemical Safety prepared a number of documents on lead risk assessment, including:

- Poisons Information Monograph (PIM) on inorganic lead (PIM 301; <http://www.inchem.org/documents/pims/chemical/inorglea.htm#PartTitle:1.%20NAME>);
- Poison Information Monograph on organic lead (PIM 302; to be updated);
- Antidote Monographs (http://www.who.int/ipcs/poisons/antidote_peer_review/en/index.html);
- Antidote Monograph on succimer (DMSA) (ready for peer review; <http://www.who.int/ipcs/poisons/dmsa.pdf>);
- Antidote Monograph on 2,3-dimercapto-1-propanesulphonic acid (DMPS) (ready for peer review; <http://www.who.int/ipcs/poisons/dmps.pdf>); and
- Environmental Health Criteria 165: inorganic lead (1995) (<http://www.inchem.org/documents/ehc/ehc/ehc165.htm>)

Other documents on lead risk assessment include the following:

- IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 87 (2006) *Inorganic and organic lead compounds* (<http://monographs.iarc.fr/ENG/Monographs/vol87/index.php>)
- Joint FAO/WHO Expert Committee on Food Additives (2000)
- *Evaluation of certain food additives and contaminants* http://whqlibdoc.who.int/trs/WHO_TRS_896.pdf
- Joint FAO/WHO Expert Committee on Food Additives (2002)
- *Limit test for heavy metals in food additive specifications: explanatory note* ftp://ftp.fao.org/es/esn/jecfa/2002-09-10_Explanatory_note_Heavy_Metals.pdf
- Joint FAO/WHO Expert Committee on Food Additives (2010)

International conventions, agreements and declarations on lead

Among the many international conventions and declarations that have acknowledged the importance of exposure to lead as a key public health issue are the following:

General framework to protect children's health from hazardous environmental exposures

This group includes the following two entries:

- Agenda 21: the Rio Declaration on Environment and Development (<http://habitat.igc.org/agenda21/index.htm>)
Chapter 25. Children and youth in sustainable development (<http://habitat.igc.org/agenda21/a21-25.htm>)
- Convention on the Rights of the Child
Adopted and opened for signature, ratification and accession by General Assembly resolution 44/25 of 20 November 1989
Entry into force 2 September 1990, in accordance with article 49 (<http://www2.ohchr.org/english/law/crc.htm>)

Conventions, agreements, declarations and other legal instruments on aspects of lead

Among the legal instruments on aspects of lead are the following:

- The 1979 Convention on Long-Range Transboundary Air Pollution on Heavy Metals (<http://www.unece.org/env/lrtap/full%20text/1998.Heavy.Metals.e.pdf>)
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal Adopted March 1989 (<http://www.basel.int/text/documents.html>)
- Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, 25 June 1998 Aarhus, Denmark (<http://www.unece.org/env/pp/documents/cep43e.pdf>)

- Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (http://www.pic.int/en/ConventionText/RC%20text_2008_E.pdf)
- Annex III: **Chemicals listed in Annex III of the Convention and currently subject to the PIC Procedure (tetra-ethyllead, tetramethyl lead)** (<http://www.pic.int/home.php?type=t&id=29&sid=30>)
- OECD Declaration on Risk Reduction for Lead 19 February 1996 ([http://webdomino1.oecd.org/horizontal/oecdacts.nsf/linkto/C\(96\)42](http://webdomino1.oecd.org/horizontal/oecdacts.nsf/linkto/C(96)42))
- Resolution No. 99/6 on Phasing out Lead in Petrol European Conference of Ministers of Transport (<http://www.internationaltransportforum.org/europe/acquis/env19996e.pdf>)
- 1997 Declaration of the Environment Leaders of the Eight on Children's Environmental Health Environment Leaders' Summit of the Eight, Miami, Florida, 5–6 May 1997 (<http://www.g7.utoronto.ca/environment/1997miami/children.html>)
- Council Directive of 29 March 1977 on biological screening of the population for lead (77/312/EEC; <http://www.legaltext.ee/text/en/T50878.htm>)
- Children's health and environment: developing action plans (2004) (<http://www.euro.who.int/document/E86888.pdf>)
- Strategic Approach to International Chemicals Management: Comprising the Dubai Declaration on International Chemicals, the Overarching Policy Strategy and the Global Plan for Action
- Adopted in February 2006 (<http://www.chem.unep.ch/saicm/SAICM%20texts/SAICM%20documents.htm>)
- Intergovernmental Forum on Chemical Safety
- The Budapest Conference on Heavy Metals (Mercury, Lead and Cadmium)
- Budapest, Hungary, 23 September 2006 (http://www.who.int/ifcs/documents/forums/forum5/8inf_rev1_en.pdf)
- The Declaration of Brescia on Prevention of the Neurotoxicity of Metals

- Brescia, Italy, 17–18 June 2006 (<http://www.unep.org/pcfv/PDF/Brescia-Declaration.pdf>)
- Fourth Session of the Intergovernmental Forum on Chemical Safety Bangkok, Thailand, 1–7 November 2003 *Protecting children from harmful chemical exposures* (http://www.who.int/ifcs/documents/forums/forum4/en/14w_f4_en.pdf)
- Fifth Session of the Intergovernmental Forum on Chemical Safety Budapest, Hungary, 25–29 September 2006 *Final Report on the side event on heavy metals, 23 September 2006* (http://www.who.int/ifcs/documents/forums/forum5/8inf_rev1_en.pdf)
- Fifth Session of the Intergovernmental Forum on Chemical Safety Budapest, Hungary, 25–29 September 2006 *Toys and chemical safety: a thought starter* (http://www.who.int/ifcs/documents/forums/forum5/03_ts_en.pdf)
- Sixth Session of the Intergovernmental Forum on Chemical Safety Dakar, Senegal, 15–19 September 2008
- Busan Pledge for Action on Children's Health and Environment, 23 June 2009 (http://www.who.int/phe/busan_pledge_vs2.pdf)

ISBN 978 92 4 150033 3

