

Protecting Children from Toxic Exposure: Three Strategies

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The terminology used in health protection has a shaping effect on the strategies that can be visualized. The vocabulary used to describe a problem may constrain the imagination of its solution and reflect limitations on conceptualizing the problem. The characterization of the effects a toxic exposure as “poisoning” or as “toxicity” has implications for which intervention strategy makes sense: clinical screening, high-risk hazard control, or all-source reduction of exposure. To a toxicologist, “poisonings” are cases in which the child has a defined pattern of symptoms corresponding to toxic effects at a mid- to high level of exposure. “Toxicity” refers to a broader spectrum of effects, and at the lower levels of exposure the child may have no specific, individual symptoms but still may be affected subclinically. At low levels of exposure, toxic chemicals may act as risk factors in the epidemiologic sense of increasing the probability of a given outcome without being the single determinant cause.

For example, cigarette smoking is a direct cause of some diseases, such as lung cancer and emphysema. It would be meaningful in some contexts to speak of “cigarette poisoning,” and occasionally the term is heard

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rhetorically. Cigarette smoking, however, is also a risk factor for other outcomes, such as heart disease. In that sense, a toxic effect of cigarette smoke is one among several factors important in the frequency of disease. If the problem of cigarette smoking is taken as one of acute or chronic fatal poisoning, there are arguments for emphasizing smoking cessation in people who have trouble controlling their tobacco habit and therefore reducing the probability of extreme effects. If the problem is defined as one of preventing chronic "poisoning," development of a "safe" cigarette to reduce the dose and therefore the probability of symptomatic "poisoning" makes sense for people who cannot quit. If it is defined as a problem of toxicity along a wide spectrum of effects, discouraging people from putting any combustion product in their mouths is a better strategy. Ideally, all three strategies and all available modalities would be used in contingent fashion, but in practice that never happens. Agencies or smoking cessation programs use one or a limited number of modalities, because the cost of running programs using all available possibilities is too great. For adults, the strategy offered depends in large part on whether the sponsoring agency or the smoker views the problem as a high-risk poisoning with a certain adverse outcome or as a lower-level toxicity that increases the risk of common diseases. This analogy is imperfect but serves to illustrate the concept.

The importance of making a distinction between degrees of poisoning and levels of toxicity is illustrated by lead. Control of lead exposure, like other hazards in developed countries, has reduced the frequency of obvious poisonings, but the problem of low levels of toxicity remains. The spectrum of lead toxicity now is known to include more subtle behavioral and neurodevelopmental effects, demonstrable on a population basis, which heavily overlap the normal distribution of ability. Lead exposure in this range therefore assumes the characteristics of a risk factor rather than a determinant cause. The strategies for prevention are different.

Poisoning versus toxicity

The difference between poisoning and toxicity is not merely semantic or stylistic. The meanings define concepts that, as will be shown, imply different prevention strategies.

To a toxicologist, the word "poisoning" means the presence of symptoms. Toxicology journals tend to be consistent in preferring the term "toxicity" [1]. Usually there is a constellation of symptoms, called a "toxidrome," that, if not unique, is characteristic for a certain toxic exposure. There are many definitions of poison but relatively few formal definitions of poisoning. An early formal definition of "poisoning" was "the evil effects of any substance," referring to clinical symptoms [2]. Although, unlike the word "poison," which usually is defined on the first page of textbooks, the word "poisoning" often goes undefined in the literature of toxicology, but its usage almost always implies visible symptoms and in lay language often implies death. The glossary for the

environmental health section of *Healthy People 2010*, for example, provides the following definition for the public: “Poisoning: An exposure to a toxic substance that produces negative signs or symptoms” [3].

Toxicity, on the other hand, is a subtler concept that represents the potential, real or unexpressed, for injury across the entire spectrum of effects. *Stedman’s Medical Dictionary* defines “toxicity” as the “quality of being poisonous, especially to the degree of virulence of a toxic microbe or of a poison” [4]. To a toxicologist, toxicity ranges from the earliest subclinical effects inducing an adaptive response to fatality. Textbooks on toxicology consistently use the terms “lead toxicity” when referring to the effects of lead [5–8]. The National Institute of Environmental Health Sciences uses the terms “poison” and “toxicity” differently in their fact sheet on lead: the section “What Is Lead Poisoning?” refers to symptomatic lead toxicity, and “What Is Lead Toxicity?” refers to relatively lower levels of exposure to lead in the body when a child’s brain is developing [9].

This usage is not restricted to toxicologists. The US Centers for Disease Control and Prevention (CDC) avoids the term “lead poisoning” in everything but the name of its Lead Poisoning Prevention program. Although the blood lead level of concern is given as 10 $\mu\text{g}/\text{dL}$ throughout the text, it is not used explicitly to define lead poisoning, and no specific definition of lead poisoning is given in the text [10]. The CDC’s most recent and authoritative document, “Lead Poisoning Prevention in Young Children” (2005) [10] explicitly states that “‘lead poisoning’ is generally understood for clinical purposes to refer to episodic, acute, symptomatic illness from lead toxicity” and uses the term only for that meaning and in historical references. The CDC regularly produces a surveillance report in the *Morbidity and Mortality Weekly Report (MMWR)* on blood lead levels in the United States, but the surveillance reports do not use the term “lead poisoning” [11]. The text refers to “high blood lead levels.” *MMWR* does use the terminology “lead poisoning” with an implicit definition in specific case reports where there are signs and symptoms [12]. Likewise, the Agency for Toxic Substances and Disease Registry, which produces authoritative toxicologic profiles for hazardous substances, does not use the term “lead poisoning” in the toxicological profile for lead. Rather it uses the terms “exposure” and “toxicity,” which are described in detail [13]. The American Academy of Pediatrics Clinical Guidelines for Lead Exposure in Children consistently uses the term “elevated blood lead levels” and avoids the phrase “lead poisoning” [14].

Not every source follows the convention of distinguishing poisoning from other forms of toxicity. A fact sheet from Region 2 of the Environmental Protection Agency states, under the heading “What Is Lead Poisoning?” that “lead is a metal that can make infants and young children ill. Many of those affected never even look sick. Sometimes children with lead poisoning can have learning disabilities and other health problems” [15]. This usage equates the spectrum of toxicity, including symptomatic illness, with poisoning but it is an exception in the technical literature.

Public education and outreach programs and public health-oriented agencies seem to prefer the term “lead poisoning.” The National Coalition to End Childhood Lead Poisoning has its definition of lead poisoning in the realm of public information: “Lead poisoning occurs when the amount of lead in a person’s bloodstream is too high” [16]. The National Safety Council has in-depth information on lead in their public literature. Unique to this organization is the glossary of terms related to childhood lead exposure, including, “Lead poisoning: The level of lead in an individual’s blood at which the CDC states that adverse health effects are bound to occur” [17]. This usage is not consistent with CDC’s own definitions. The term “toxicity” is not given in this glossary, and the definition of poisoning obviously does not require symptoms.

Implications for lead

Nowhere is this semantic distinction more important than in preventing lead toxicity.

The terms “lead toxicity” and “lead poisoning” tend to be used interchangeably in pediatric practice and public health. This usage is understood to be in part rhetorical and in part philosophical, because the word “poisoning” communicates a sense of urgency, and any degree of avoidable toxicity is unacceptable. It is useful to keep the concepts straight, however, because the meanings are subtly but importantly different, and “toxicity” is the more general term.

Lead poisoning, in the classic, syndromic sense, is now rare. Cardinal symptoms of pediatric lead toxicity include acute encephalopathy, colicky abdominal pain, projectile vomiting, ataxia, and a combination of irritability and lethargy. Such cases have a poor prognosis for full recovery because they are associated with long-term, symptomatic neurologic impairment. Lead poisoning in the classic sense, as used by toxicologists, is controlled by removing sources of exposure that result in symptomatic disease. This approach implies a strategy based on identifying and removing the sources of catastrophic toxicity. Paradoxically, this approach may not do much to reduce mean lead levels in a population.

Historically, the main sources of lead exposure for children in the United States were interior leaded paint, emissions from leaded gasoline, and, in some places, residual lead from primary or secondary smelting activity. The ban on interior leaded paint in 1978 led to a sudden and marked reduction in cases of symptomatic lead poisoning in the United States [18] that has continued to the present day. The residue of lead paint in older housing continues to be a threat to many children, however, especially in cities with older housing stock, such as Washington, DC. The most important sources of lead today are lead paint and, occasionally, lead-contaminated toys. Some consumer products still may contain lead (eg, low-temperature glazed pottery, Ayurvedic medicines, kohl [the South Asian cosmetic], and certain

plastic products in which lead is used as a stabilizer), and lead may, rarely, be present in the ink on labels for food products (recently a problem with imported candies). Each of these sources may place the child at risk for acute or chronic, symptomatic toxicity—the condition toxicologists recognize as poisoning. They result in sporadic cases of often severe disease in a relatively small number of children. Removing these sources of lead may reduce the frequency of lead poisoning cases but may have little effect on mean lead levels for the population or the risk of low-level lead toxicity in most children.

Mean blood lead levels in the United States were much higher in previous generations and continue to fall for all ages. Today, the “average” (actually, the geometric mean) blood lead level for American children is about 2 $\mu\text{g}/\text{dL}$ [19], probably the lowest it has been for a century, at least in urban areas [18]. This drop in blood lead level may have unmasked relationships between blood lead and low-level toxicity that were not obvious before. For this reason, there has been increasing concern in recent years about the toxicity of lead at lower exposures and about lead as a risk factor for child health and development [20].

Other environmental sources of exposure to lead, such as the persistent residue from leaded gasoline, contribute to high lead levels in dust in homes, which is a major contributor to elevated blood lead levels. The ban on leaded gasoline in 1986 resulted in a rapid and steady decline in the average blood lead level in children, increased the margin of safety, and therefore reduced the likelihood of acute poisoning [18]. The residue of lead in soil contributes to background exposure in urban areas, however, and therefore contributes to body burden and mean lead level. Other secondary sources include food, drinking water, and soil. These sources are highly unlikely to result in lead poisoning, in the classic toxicologic sense, but may contribute to the elevation of blood lead and total body burden. Removing these sources of lead may reduce mean lead levels but probably will do little or nothing to reduce the frequency of symptomatic lead poisoning where it remains a problem.

The CDC has established the “level of concern” for children at 10 $\mu\text{g}/\text{dL}$; all children should be below this level, especially at the critical age of 2 years. Most experts, however, now believe that this level of concern is too low because evidence for neurodevelopmental effects, in the form of group differences in IQ and academic achievement and a higher probability of behavioral abnormalities (including aggression), have been demonstrated even below this level [20–24]. The effects are proportional to blood lead levels and show no evidence for a threshold, suggesting that the lower the lead level is, the better [25]. These are group effects: it is not possible to establish an effect for a particular child. Indeed, for the individual child, an effect associated with lead exposure cannot be discerned; the individual child may fall within the normal range. For this reason, the toxicologist normally would not use the word “poisoning” and would prefer the word “toxicity”

because the effect is in the range of toxic effects but also may be within normal limits.

At lower levels of toxicity, exposure to a toxin may be one factor among many in a multifactorial model and may not necessarily be the most powerful risk factor. At ambient environmental levels, exposures to such hazards, including lead, cease to become threats in the toxicologic sense or etiologic causes in the clinical sense and become instead risk factors in the epidemiologic sense, one of many determinants. For example, in the case of subclinical neurotoxicity resulting in learning and behavioral effects, lower-level lead exposure may be one among many environmental determinants, including mercury, arsenic, endocrine disruptors (thyroid hormone mimics), inadequate omega fatty acid intake, inadequate early child stimulation, and a myriad of other influences on early childhood development [26]. Sorting through these various risk factors to ascertain which are most important and which have relatively small effects is the work of epidemiology informed by toxicology. At present, however, it is not possible to estimate attributable risks reliably [27].

Three general protective strategies

There are three basic strategies to protect children: individual intervention, the preventive medicine strategy, and the public health strategy. The latter two are defined here as they were by epidemiologist Rose [28], who developed the concepts with cardiovascular disease in mind.

The first strategy is the individual approach, focused on the individual child. Applied to lead, the individual approach is a lead-poisoning prevention and mitigation strategy. The individual child must be protected by the parent or guardian, family, and immediate community; the basic strategy is through education. Most pediatricians do not have time to educate the parents themselves and so depend on public health-oriented agencies and patient education materials. Protection must be undertaken within the family and focused on identifying and eliminating the specific sources of exposure that the child may encounter. Because neither pediatrician nor public health agency can be omnipresent, the first line of protection is the parent or guardian. To prevent lead poisoning, children are individually protected in or removed from homes where a hazard exists, on a case-by-case basis, but placing such responsibility on the parent is not reliable. The pediatrician may suspect a problem, and an elevated blood lead level confirm the suspicion, but if the child is symptomatic much damage has already been done. In this situation, it may be possible to prevent future disability resulting from further exposure (“tertiary prevention,” in the language of public health), but it is too late to prevent the initial injury from past exposure (“primary prevention”) [29,30].

The preventive medicine model is based on identifying individuals at high risk and then intervening one-on-one. Applied to lead, this is primarily a lead-poisoning prevention strategy that also reduces the risk of lead

toxicity at lower levels, reducing its role as a risk factor for subclinical manifestations in children with slightly or nearly elevated blood lead levels. Identification necessarily requires a screening step, which in the case of lead toxicity is the routine blood lead level. Children in circumstances at high risk for symptomatic poisoning must be screened to be identified, and this information is conveyed to a system that then provides an intervention at the level of the individual child, usually mitigation of exposure to lead paint in the home. When the blood lead level is slightly rather than highly elevated, there is both the risk associated with lower-level toxicity and an increased risk of symptomatic poisoning, because the margin of safety for symptomatic poisoning is reduced (ie, less additional lead intake would be required to push the blood level into a range associated with higher levels of toxicity). Poisoning can be prevented by an intervention that both prevents a future increase in blood lead and reduces the risk of subclinical toxic effects for that particular child. This strategy therefore is protective against the future adverse outcome of poisoning or continued accumulation of subclinical effects ("secondary prevention") but comes too late to avoid the subclinical effects, which may already have been sustained.

Ideally, the preventive medicine model would screen houses, not children. Public health agencies have used elevated blood lead levels in children to identify housing with a lead paint problem. This approach is inappropriate. It is far better that houses be screened systematically for children's risk of lead exposure from living in unsafe homes; such screening would prevent clinical lead poisoning. Housing should be made safe for children; bad housing should not be identified by screening children. Children should not be used as markers to identify housing problems. Unfortunately, it is difficult to screen houses because of private property ownership rights and the right of access, the resources that would be required, and the very limited mandate of public health agencies when it comes to private homes.

The public health model is based on reducing risk for all members of a population, whether they are at high risk or not. Applied to lead, this approach is a lead toxicity prevention and elimination strategy. Concern for children today centers on reducing lead levels to as low as possible for all children. For background lead exposures, such as those described, the only practical intervention is to reduce exposure of all children in the population, treating the exposure as a risk factor. Children exposed in a multifactorial model may have a higher risk as a result of low levels of exposure, but their overall risk may be greater or less than that of other children, depending on their total risk profile. In the public health model, the benefit of investing limited funds in programs to reduce exposure to one risk factor must be compared with other potential investments (eg, reduction of exposure to mercury) on the basis of practicality, feasibility, and resources available.

Ideally, public health agencies should implement all three strategies. In practice, they cannot. Where should priorities be placed? Washington,

DC, provides an example. It is an old city with an unremediated housing stock. For such cities, it may be necessary in the short term to concentrate on preventing lead poisoning, a goal that, paradoxically, may not be achieved by lead elimination strategies alone. Mean blood lead levels continue to fall in Washington [31], as in the rest of the country [19], showing that lead intake from other sources is declining overall. The persistence of elevated blood lead levels and rare instances of symptomatic lead poisoning demonstrate that the major sources of lead have not yet been adequately controlled, however.

Lead elimination efforts have no obvious end, because in the modern environment there always will be sources of lead, released and deposited since the Industrial Revolution, and there is no threshold at which point remediation can be called entirely effective. Eventually, in public health agencies lead elimination efforts will come into budgetary and resource competition with efforts to reduce other risk factors for neurobehavioral outcomes and other public health priorities.

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