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MEDICAL PROGRESS

VULNERABILITY OF CHILDREN TO LEAD EXPOSURE AND TOXICITY
(First of Two Parts)

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LEAD poisoning in adults is largely an occupational hazard that can be kept under reasonable control, and the source and degree of exposure are generally known. In recent decades, improvements in industrial methods and in occupational health standards, such as institution of periodic examinations of exposed workers for early evidence of undue lead absorption, have reduced severe occupational lead poisoning considerably, particularly in the larger industries. In contrast, childhood plumbism generally occurs as accidental poisoning among young children who cannot be kept under constant surveillance. Although peeling lead-based paint in old houses has been implicated as the *major source of severe exposure among children*, the source of poisoning, in many cases, remains undetermined.[1-4]

Lead poisoning caused by paint ingestion in infants and children was reported in the Australian literature around the turn of the century[5] and gradually gained recognition in the United States as a public-health problem in the 1920's, when pica was linked to its occurrence.[6-9] Despite the appearance of scores of papers in the medical literature in the ensuing years describing hundreds of cases with a formidable mortality and morbidity,[10-31] there was little systematic effort to deal with this problem. When titanium oxide began to replace lead pigments in interior paints in the 1940's, many thought that lead poisoning in children had become a problem of the past, not realizing that millions of houses still had lead-based paint on them, and that exterior lead paint and other lead sources may also pose a hazard.[4,32] Thus, unlike industrial plumbism, the childhood lead-poisoning problem remained essentially unchanged for about half a century, during which only a few cities made limited attempts to deal with it.[16,17,22,27-29]

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In the late 1960's, the public as well as health workers suddenly awoke to the fact that lead poisoning was still taking a high toll among children in many areas.[36] A long-neglected fact also became obvious: lead poisoning in children, as in adults, is in fact a preventable illness. After this awakening, many cities set up or expanded screening programs for the detection and treatment of children with lead poisoning. Much had been known about the epidemiology of childhood lead poisoning by the late 1960's,[3,17,29] but data collected since then have revealed some new facts that few were prepared for.

A recent survey of 21 screening programs that tested a total of 344,657 children between 1969 and 1971 revealed that 8.8 to 32.9 per cent had blood lead levels of 40 μg per 100 ml or more — levels indicative of undue lead absorption.[37] The overall average percentage of children found in these programs to have such lead levels was 26.1, which is not essentially different from that reported earlier by a few programs.[38] In this survey, 0 to 19.4 per cent of the children screened had blood lead levels of 60 μg per 100 ml or more, and 0 to 7.6 per cent had levels of 80 μg per 100 ml or more — levels designated by the United States Surgeon General as constituting "unequivocal cases of lead poisoning" to be handled as medical emergencies.[39] It should be noted that these figures are based on testing of preselected populations, most of whom are from old and poorly maintained neighborhoods, but they do reflect the gravity of the problems of undue lead absorption and lead poisoning in children in many areas of the United States today.

Perhaps even more surprising to many is the recent finding that these phenomena, earlier thought to be found only in the "inner cities" or "lead belts" or "urban slums," are now reported to be no longer so well confined. In Baltimore, screening results in the five-year period 1966 through 1970 showed 43.3 per cent of children with blood lead levels of 60 μg per 100 ml or more came from outside the so-called "inner city." In 1971 and 1972, 38 per cent of the children found to have blood lead levels of 40 μg per 100 ml or more came from such outer areas. Of 19 cases of childhood lead poisoning reported to the City Health Department during this period, 11 were from the inner city, and eight from other areas.* Philadelphia also found recently that approximately 50 per cent of the reported cases of childhood lead poisoning are located outside what was formerly referred to as the "lead belts" or "inner city." Some came from census tracts where the property values were equal to or greater than that of the average property value of most dwelling units in the city of Philadelphia, indicating that this health problem is not necessarily found only in the "slums."† As these cities began to cover areas not conventionally thought of as "lead belts," the previously well defined boundaries of these areas began to disappear. It has also been suggested that with replacement of the old inner-city dwellings by urban renewal and other modern construction, the location of reported cases has moved outward to other parts of the cities.[3]

Furthermore, as screening programs were launched in smaller cities, it became apparent that absorption of excessive amounts of lead is not limited to children in large urban areas. A 1971 Illinois survey involving 6151 children one to six years old living in 14 cities of intermediate size (10,000 to 150,000 population) revealed that 18.6 per cent had blood lead levels of 40 μg per 100 ml or more — a figure similar to that reported in large urban cities; 51 children (0.8 per cent) had blood lead levels of 80 μg per 100 ml or more.[40]

Nor is the problem prevalent only in the eastern part of the United States as some had thought. A 1971-1972 survey of 27 cities in 23 states located in the Midwest, South, West, North and East of the country, involving 2309 children, revealed that children with blood lead levels of 40 μg per 100 ml or more were found in all but four cities. In the cities where no such children were found, only a very limited number were tested.[41]

Even children living in rural areas are not spared from this health problem, though the prevalence appears to be lower. A recent survey of 230 rural children one to five years old from Dutchess County, New York, and Litchfield County, Connecticut, revealed that 20, or 9 per cent, had blood lead levels in excess of 40 μg per 100 ml, and values as high as 70 μg per 100 ml were found. Ninety-one per cent of the children tested were white, and some came from middle-class and upper-middle-class homes.[42]

The importance of undue lead absorption in children has previously been reviewed.[38] It is frequently the prelude to actual lead poisoning; unless further hazardous exposure is terminated, poisoning will occur in one to two months.[38,43] Its recognition is therefore vital to the prevention of lead poisoning. Moreover, young children may be particularly vulnerable to lead toxicity, and deleterious effects may occur in the absence of overt clinical evidence of poisoning. Several recent studies suggested that the frequency of intellectual impairment and other psychologic deficits appeared to be increased among children with evidence of undue lead absorption who were not thought to have lead poisoning.[44-47] Others reported that anemia is common even in those with blood lead concentrations of 37 to 60 μg per 100 ml — levels that have often been accepted as harmless in the past.[38]

Studies of blood lead levels in adults comparable to those in children cited above are not available. However, undue lead absorption is unlikely to be as prevalent among adults as in young children, except in those who are occupationally exposed. A 1961 survey of blood lead levels among adults in six cities (New Orleans, Dallas, Denver, Chicago, New York and Cincinnati) revealed that of 735 samples tested, 2.7 per cent were over 40 μg per 100 ml.[48] In a survey of 106 persons in downtown Philadelphia, 2.8 per cent had such levels

*Schucker GW: Baltimore City Health Department, personal communications.

†Sobolesky, WJ: Philadelphia Department of Public Health, personal communications.

None of 81 persons from suburban Philadelphia had levels exceeding 40 μg per 100 ml.[56] Among those occupationally exposed, the figures varied from 12 per cent in service-station attendants to 67 per cent in garage mechanics in this survey.[56]

Lead is a ubiquitous trace element in modern man's environment; exposure to it is inevitable, even for the unborn fetus.[51,52] But what accounts for the much higher prevalence of undue lead absorption among young children? Can exposure to peeling lead paint in old houses explain this phenomenon adequately, or are children exposed to a number of other hazardous lead sources? Are children more vulnerable than adults to the same type of exposure? And perhaps even more important, are they more susceptible to the toxic effects of this potentially lethal element? If so, what might account for it? The following is an attempt to find at least partial answers to these questions.

Lead Exposure in Children

Lead-Based Paint

The literature generally indicates that the source of exposure in childhood lead poisoning is almost invariably peeling lead paint and broken lead-impregnated plaster found in poorly maintained old houses.[2,27,28] A careful review of a number of reports, however, left some cases unaccounted for. Christian reported that of 926 children with lead poisoning seen between 1959 and 1964, only 575, or 62 per cent, were known to have ingested paint.[53] Of 1155 children treated for lead poisoning in Chicago between 1967-1968, 78 per cent gave a positive history of pica for paint and plaster.[54] Some children with a negative history are found to have positive abdominal x-ray studies and deliberate denial by parents or failure to observe such ingestion must account for such cases. But for a number of children, other sources of exposure cannot be ruled out completely.

Furthermore, analysis of paint in homes of children with lead poisoning has not consistently revealed a hazardous lead content. Tyler reported that of 5466 samples of paint obtained from the home environment of lead-poisoning victims in Philadelphia between 1961 and 1963, only 57 per cent yielded positive findings, defined as paint with more than 1 per cent lead.[55] In 1971, a potential source of lead was uncovered in 76.1 per cent of the paint samples obtained from New York City dwellings in which children with lead poisoning lived.[56] Paint with 1 per cent lead cannot be considered safe, and the negative results may to some extent reflect a sampling problem, since repeat investigation often yielded more positive results. Also, dwellings other than the children's homes where they may spend considerable time are often not known to the investigators. But, again, the possibility of other sources of hazardous exposure must be considered.

The above data should not be construed as incontrovertible evidence that children with a negative history of ingestion or negative findings on housing inspection did not get poisoned from lead paint, but should serve to broaden perspective on the problem and stimulate investigation into other possible sources of hazardous exposure. Some sources occasionally implicated include lead paint on furniture, toys and other items easily accessible to children, improperly glazed earthenware, lead fumes and ashes produced by burning lead-battery casings, and other miscellaneous items.[24,25,28,31,57-61] In recent years it has also become increasingly apparent that a number of sources other than those mentioned above may contribute appreciably to the lead intake of young children and may even be a means of poisoning. An outstanding example is the extremely high lead content of street dirt and surface soil in many cities.

Dust and Dirt

A 1971 Midwestern city survey found the average lead concentration in dirt collected from residential sites to be 1636 μg per gram, and that from commercial sites to be 2413 μg per gram.[62] In 1972, a study of lead content of street dirt in Washington, D.C., revealed an alarming concentration of 12,820 ppm (12,820 μg per gram) in samples collected from a very busy downtown intersection; lesser but still remarkably high concentrations of 4000 to 8000 ppm were found in samples from many other sites.* Surface soil in some city parks also has very high lead content. Samples collected from MacArthur Park in Los Angeles, for example, were found to have a lead content of 3357 μg per gram.[62] In Charleston, South Carolina, a survey showed that soil lead values varied widely from 1 to 12,000 ppm; values of over 1000 ppm were found in samples taken from the yards of 11 of 13 houses where childhood lead poisoning had occurred, suggesting a possible relation between lead in dirt and poisoning in children.[63] Household dust samples in the Boston area have been found to contain 0.1 to 0.2 per cent (1000 to 2000 ppm) lead.[57]

Sayre et al. recently investigated house and hand dust as a potential source of lead exposure in children. They found not only that inner-city children have higher mean blood lead values than suburban children but that the lead contents of dust collected from homes and hands of the former are significantly higher than that of the latter, and that there is a definite relation between individual hand and household dust lead contents. These investigators suggested that among inner-city children, hand-to-mouth activity could easily result in ingestion of a considerable amount of lead.[64]

The importance of the high lead content of dust and dirt can be viewed in its proper perspective by consideration of the daily permissible intake of lead for children one to three years old, which was set at 300 μg by a Public Health Service ad hoc committee in 1971.[65] This level was specified without benefit of later data indicating a greater gastrointestinal absorption and retention of lead in children than in adults. The average daily intake of lead from diet and air among young

*Fritsch AJ: Personal communication.

children probably amounts to one-half to two-thirds of the daily permissible intake, thereby leaving a very narrow margin of safety.[65] Recently, Barltrop and Alexander suggested that the daily lead intake in young children be limited to less than 300 μg.[66,67]

Sucking dirty fingers, eating with unclean hands, consumption of food items dropped on the ground and mouthing toys or other objects coated with dust or dirt are common practices among toddlers and young children. For those who reside or play in an environment where dust and dirt of high lead content are readily available, it is not unrealistic to speculate that ingestion of an amount exceeding, and even many times, the daily permissible intake could be a common occurrence. For children with pica for dirt, the grave danger of exposure to dirt of high lead content is obvious. One should, however, not lose sight of the fact that lead content of dirt, expressed in parts per million, is relatively low as compared to that of old lead paint, which often amounts to 5 to 40 per cent or more of the final dried solids.[3]

Ambient Air

Ambient air is another source of lead exposure among urban dwellers. Lead concentration in ambient air varies inversely with altitude,[68,69] and devices used in measuring air lead concentration are rarely, if ever, placed at the height at which young children breathe. This fact is seldom given consideration in calculations of the respiratory intake of lead among young children. One study indicated that lead concentration at 20 meters above the ground is only half the amount obtained at 1.5 meters.[69]

Miscellaneous Sources

A number of lead-containing items may not be a source of exposure among adults can be a real danger among young children with pica and those with increased oral activity. Newspapers, magazines and children's books with ink of high lead content are good examples. A recent survey showed that certain yellow, red and orange colors used on newsprint yielded lead contents of 1000 ppm or more. One sample had a lead content of over 4000 ppm.[70] Children with lead poisoning who gave a history of eating pieces of newspaper rather than paint have been cited.[71]

Other miscellaneous sources include lead in the paint coating of pencils, which poses a hazard for children who habitually chew on their pencils. Lead content as high as 12.5 per cent has been reported in such paint.[72]* Chewing of toothpaste tubes and ingestion of toothpaste with high lead content have been cited as another mode of hazardous exposure among children. Surveys of toothpaste, toothpaste tubes, and coatings of the tubes have revealed that the lead content of the outer coatings of some tubes exceeded 5 per cent, and some toothpastes in contact with the tubes had lead contents of 180 μg per gram or more.[73,74] Some canned infant food and evaporated milk have also been found to contain appreciable amounts of lead.[3,66]†

*The Pencil Makers Association, representing 90 per cent of the U.S. producers, has announced the establishment of a certification program to ensure that lead in member companies' pencil paint does not exceed 1 per cent.

†Since January 1, 1973, there has been a co-operative FDA-industry quality-assurance program covering all evaporated-milk plants in the nation to limit lead content of such products to less than 0.5 ppm. At the recommendation of the FDA, the infant-food manufacturers are actively developing methods to improve their cans and reduce lead content of canned infant food.

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