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The health impact of environmental pollutants: a special focus on lead exposure in South Africa

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Abstract

Studies have shown blood lead levels of some children in South Africa at levels of health concern. New studies show even relatively low lead levels to have detrimental effects on cognitive function in young children. Large numbers of South African inner-city and other children have been shown to have unacceptably high blood lead levels. Studies indicate that blood lead levels of children living in South Africa's urban areas are higher than those of children in most developed countries, including Great Britain, Europe, and the United States. Although data and reported studies are very sparse, mean blood lead levels of approximately 15 μg/dl have been reported in children. Elevated blood lead levels were associated with socioeconomic status and housing conditions. Key environmental risk factors for elevated blood levels were contaminated soil and dust in the urban environment, and the still large number of automobiles using leaded gasoline.

In view of emerging evidence linking lead at increasingly lower levels to adverse effects in children, the South African government is taking actions to reduce lead exposure among vulnerable groups. Currently, South Africa has no national lead surveillance program. The government, therefore, has developed international and regional partnerships to prevent and address the problem of lead exposure.

Key words: South Africa – lead exposure – children health

Introduction

The Republic of South Africa is a middle-income, developing country in which decades of apartheid rule have contributed to conditions of poverty, inequity, and exposure to environmental toxicants along racial lines. Despite an abundance of natural resources and a well-developed infrastructure, economic growth has been slow, and poverty and unemployment remain serious problems. A national census undertaken in 1996 determined the population to equal 40.6 million people, distributed into just over 9 million households, of which 54% were in urban areas (SSA, 1998). A process of rapid, unplanned urbanization has been under way in recent decades, associated with the formation of sprawling informal settlements on the periphery of towns and cities, and urban degeneration and crowding in inner-city area. The public transportation system is weak, with a heavy reliance on road-

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based modes. On average, vehicles in South Africa are older than in developed countries and, consequently, associated with higher levels of pollutant emissions.

The mining, smelting, and other processing of South Africa's rich mineral resource base has contributed in large part to many of the country's current environmental and health concerns. According to Dr. Manto Tshabalala-Msimang, the South African Minister of Health, South Africa's mining industry has, since its inception, been a backbone of South Africa's economy. However, the wealth generated by mining throughout the past 120 years has been supported primarily through a system of migrant labor (associated with the disintegration of family structures and concomitant social concerns), made up mostly of black workers, working under unsafe and unhealthy conditions, for low wages (Mathee et al., 1996). Mining products and processes have also placed workers and their families at risk of exposure to environmental contaminants, for example, lead.

Exposure to lead is not, however, restricted to workers in the mining and smelting industries. A nationwide health and nutrition survey undertaken in the USA showed a clear association between the prevalence of elevated blood lead levels and the degree of urbanization of the population (NAS, 1980). During recent decades rapid and unplanned urbanization has been under way in South Africa. Data from the 1996 national census indicated that about 54% of the population was urbanized, increasing the potential for this group to become exposed to lead in the environment. Most urban populations rely heavily on automobiles. With transportation being strongly skewed toward road-based modes in South Africa, vehicle-related air pollution has been an increasing concern in recent years. At present, most of the gasoline used in Africa contains lead. While varying from one country to another, the lead content of gasoline in African countries overall is considerably higher than the 0.15 grams per liter being adopted by the European Economic Community; in Canada, the United States, and Japan most of the gasoline is unleaded (Nriagu, 1991). Nriagu reported that the consumption of gasoline in Africa is estimated to be 6×10^{10} liters/year. It was assumed that the gasoline lead content equaled 0.3 – 0.6 g /l, and the total consumption of lead in gasoline was estimated to be 1,800 – 3,600 metric tons/year. Developed countries have reduced or phased out leaded gasoline, but consumption of leaded gasoline in Africa has not decreased appreciably. While unleaded gasoline was made available in South Africa in 1996, leaded gasoline currently comprises about 75% of the gasoline market share in the country.

Among the strategies to address environmental concerns in South Africa has been the development of international relationships that promote increased regional and international cooperation. The cornerstone of South Africa's relationship with the United States is the Binational Commission (BNC), which promotes ties between the two countries across a broad spectrum of trade, business, human resource, energy, environmental, and scientific and technological issues. The BNC provides a mechanism for South Africa's central government, and its environmental institutions, to assist in protecting the public from exposure to environmental contaminants, including toxic metals. A South Africa-USA Memorandum of Understanding (MOU) under the umbrella of the BNC includes provisions for the Agency for Toxic Substances and Disease Registry (ATSDR) and other federal agencies to assist in strengthening and expanding cooperation in occupational and environmental health.

In this paper we briefly discuss the problem of childhood lead exposure in South Africa, summarize the approaches to addressing this issue, and discuss expected changes in national and international policies that may impact these efforts.

Lead exposure in South Africa

The uptake of lead from the environment, and the implications for child and fetal health especially, has been a global public health concern for decades (Tong et al., 2000), including the potential for effects on neurologic development and behavior. With an increasing body of evidence, developed over decades and in a wide range of settings, on the health effects of exposure to lead – even at very low levels – many countries have taken action to reduce children's environmental exposure. These actions have included, for example, establishing national surveillance and screening programs; developing blood lead standards or action values; developing environmental lead standards or guidelines; removing lead from gasoline, pigments, and paints; and establishing soil abatement and personal and environmental hygiene programs. For the most part, however, actions to reduce environmental lead contamination, and children's exposure, have been implemented most vigorously and successfully in developed countries.

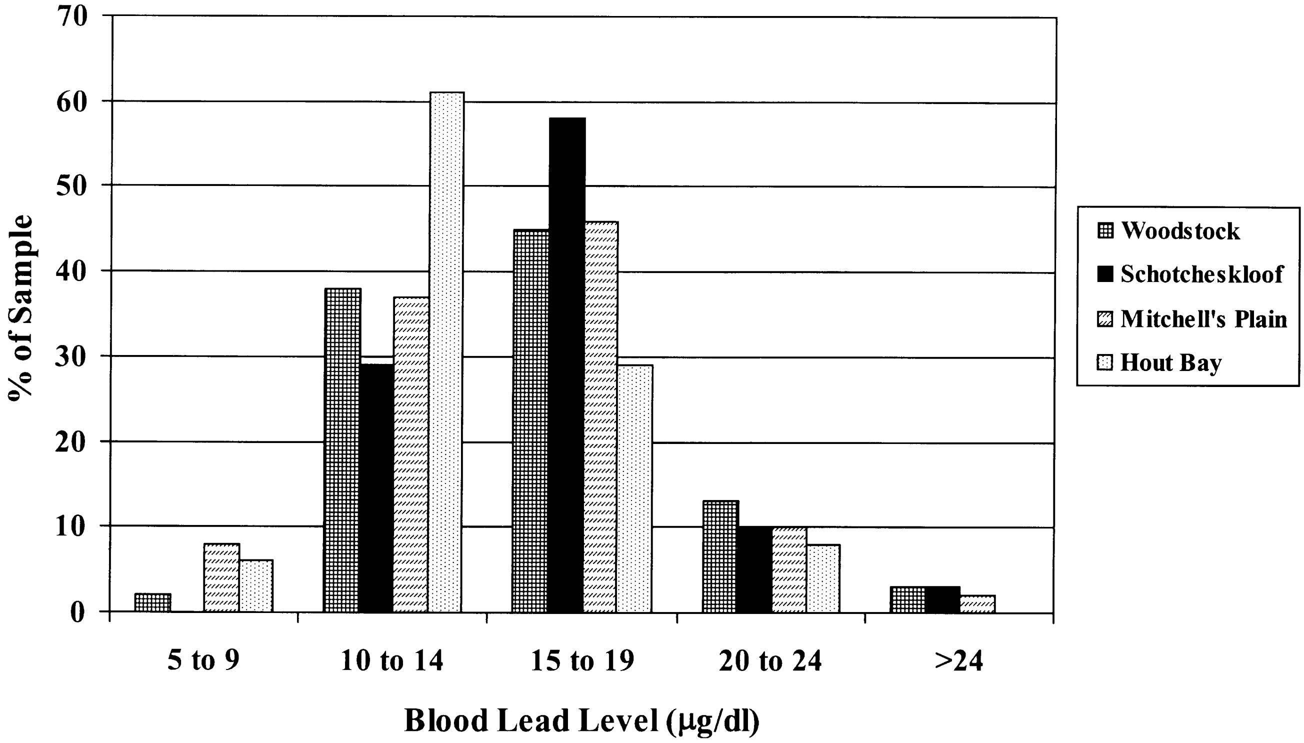

Fig. 1. Blood lead distribution in Cape Town (von Schirnding et al., 1991).

There are many sources of lead in South Africa. Currently, two active mines contribute to South Africa being among the major providers of lead on the global market. While no primary lead smelters exist, four secondary smelters are key to the extensive lead recycling activities under way in the country. Unleaded gasoline has been available since 1996; however, its use as a replacement fuel has been slow, and unleaded gasoline currently constitutes only about 25% of the gasoline market share in the country. There are concerns also about childhood exposure to lead from peeling paint in aging buildings such as schools and housing, especially in older townships and inner-city areas. Lead is also used in a wide range of other processes and products in South Africa, for example, ammunition, wheel balancing weights, batteries, cabling and protective clothing, and for various recreational purposes (von Schirnding et al., 2001).

Although South Africa has no national blood lead surveillance program, epidemiologic studies undertaken in various parts of the country indicate that certain groups of South African children have unacceptably high blood lead levels. For example, the first major epidemiologic study of childhood blood lead levels undertaken by von Schirnding and coworkers in the 1980s showed that children living in an inner-city area had a median blood lead level of 16 µg/dl, with coloured children having higher blood lead levels than their white counterparts.

A repeat blood lead survey, carried out in 1991 in the same area, showed little change in the blood lead distribution of children had occurred, despite a reduction in the gasoline lead content to 0.4 g/l (von Schirnding et al., 2001) (Figure 1). There was a strong association between elevated blood lead levels and the proximity of schools with respect to traffic density (von Schirnding et al., 1991).

Table 1 gives the mean and median blood lead levels by area (suburb). It is evident that variations in blood lead concentrations occurred between individual schools in the inner city suburb of Woodstock, where median school blood lead levels ranged from 13 to 19 µg/dl. At school 6, situated in the immediate proximity of a busy highway, the highest blood lead levels were registered, with 78% of children having blood lead levels equal to or greater than 15 µg/dl. Blood lead levels measured at school 9 in the inner city suburb of Schotcheskloof were lower (averaging 15 µg/dl). Blood lead levels at school 10, situated in suburban Hout Bay, were substantially higher in 1991 then in a previous study done in 1984. This may reflect urbanization trends and increased traffic densities in the area over the past 10 years. Von

Schirnding concluded that the inner-city environment sources of lead are ubiquitous, with elevated levels found in air, dust and paint, in the environment at large and in the home environment in particular. In light of other contributing factors associated with elevated blood lead levels in inner-city children, von Schirnding concluded that it is possible that more measurable impacts on blood lead levels in South African children will be seen in outlying areas, where there are fewer competing sources of exposure. Therefore, the blood lead levels of the suburban children should serve as a useful baseline against which to measure the current situation regarding lead in gasoline in South Africa (von Schirnding et al., 1991).

Table 1. Mean and median blood lead levels (μg/dl), by school – 1991.

School	N	Median	Mean
Woodstock			
1	19	17	17
2	37	16	17
3	68	16.5	16
4	43	13	13
5	14	15	16
6	37	19	19
7	25	15	16
Schotcheskloof			
9	48	15	15
Mitchell's Plain			
13	104	15	15
Hout Bay			
10	20	14	14
11	70	13.5	13
12	25	14	14

In a study of 477 first grade school children undertaken in Johannesburg during 1995, the blood lead distribution ranged from 6 to 26 μg/dl, with the mean level equaling 11.9 μg/dl. The blood lead levels of 78% of children equaled or exceeded 10 μg/dl, the current international action value. Various indicators of socioeconomic status, for example, living in an informal dwelling, were significantly associated with elevated blood lead levels (Mathee et al., 1996).

During 1990, a study of cord blood lead levels among newborns in Johannesburg/Soweto determined a mean level of 5.9 μg/dl, and a range of 2 to 20 μg/dl (Figure 2). The cord blood lead distribution was positively skewed, indicating a proportion of newborns who had been exposed to lead during the fetal stage. Cord blood lead levels were significantly associated with socioeconomic status, maternal age, maternal work status, household crowding, and perhaps some hematological factors (Mathee et al., 1996). Studies have shown fetus development to be

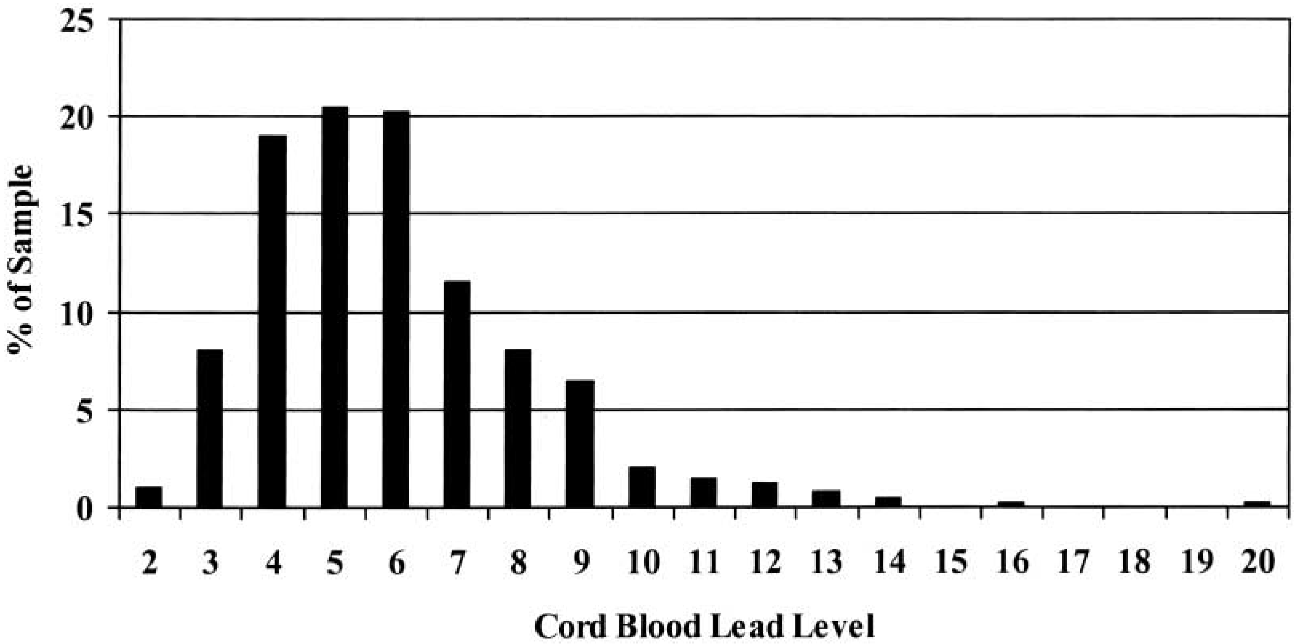

Fig. 2. Cord blood lead distribution in Soweto/Johannesburg – 1990 (Mathee et al., 1996).

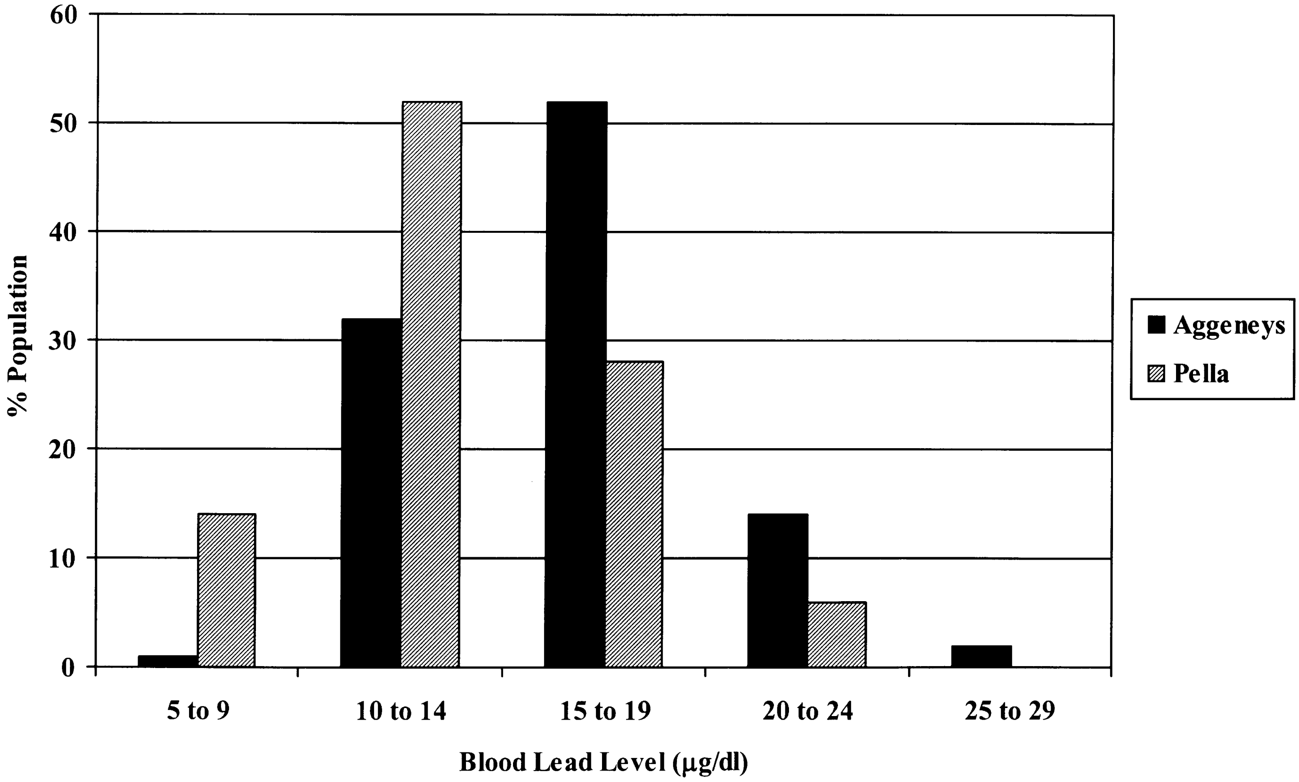

Fig. 3. Blood lead distributions in a South African lead mining (Aggeneys) and comparison (Pella) town – 1991 (von Schirnding et al., 1991). Aggeneys: n = 86; Pella: n = 68.

highly sensitive to lead exposure during development (Mathee et al., 1996).

Blood lead levels of children living in a rural lead mining and a comparison village have also been ascertained (von Schirnding et al., unpublished data). Despite higher socioeconomic status, children from the lead mining village had significantly elevated blood lead levels compared with their counterparts in the comparison village (Figure 3). For example, blood lead levels in Aggeneys (the mining village) averaged about 16 μg/dl whereas in Pella, a village about 40 kilometers away, mean blood lead levels were about 13 μg/dl. Within Aggeneys, fathers working in the mine were found to constitute a pathway of exposure to lead among their children, in that they brought lead particles home on their clothing, hair, and shoes.

The lead levels found in the rural children were far higher than expected. Further studies are needed to establish whether these levels apply also to other rural areas of South Africa, and if so, the source, of the pollution. It appears from the data that lead contamination is so pervasive that even persons living in rural areas may carry an appreciable load (Kibel et al., 1993).

Blood lead level comparison with other countries

Overall blood lead levels of the Cape urban children measured in studies appear to be considerably higher than those of urban Australian and European children, where blood lead levels now average well below 10 μg/dl (Schutz et al., 1989; Cowie et al., 1997). Results from the Third National Health and Nutrition Examination Survey (NHANES) study in the USA indicate that blood lead levels are now averaging around 3 μg/dl (Brody et al., 1994). In certain European countries and the USA, blood lead levels have been steadily decreasing over time, in some instances in direct proportion to decreases in lead concentration of gasoline and other sources of exposure (Annest et al., 1983).

Health effects associated with lead exposure

Elevated blood lead levels are associated with a wide range of health effects in children. These include reductions in intelligence quotient, behavioral effects such as hyperactivity, an inability to concentrate, poor school performance, anemia, and abnormal development of organs such as the heart, liver, and kidneys (ATSDR, 1999). For children, the Centers for Disease Control and Prevention has defined an elevated blood lead level as >10 μg/dl, but some evidence is beginning to mount of adverse health effects at even lower levels. In one study, Emory et al. (1999) found neurobehavioral effects at blood lead levels >10 μg/dl in human neonates.

Childhood lead poisoning is a preventable disease and a major international issue (Falk, 2002). The removal of key lead sources and prevention of exposure in the United States have led to dramatic decreases in the population blood lead levels and instances of severe lead poisoning requiring treatment. In South Africa and other developing countries, childhood lead poisoning will remain a concern as long as focal sources remain that cause exposure. According to Falk (2002), the challenge will be for developing countries to implement effective national and regional efforts to address their specific sources of lead.

Risk factors for elevated blood lead levels

A number of environmental and sociodemographic factors were significantly related to children's blood lead levels in South Africa (von Schirnding et al., 1991). Among the environmental variables, elevated blood lead levels were associated with residence in dusty homes and homes in a poor state of repair. Other environmental factors may include exposure to lead-based paint, petrol-derived aerosols, and lead plumbing. Children take in the dusts/soils by mouthing of fingers, palms, and various objects; eating with dirty hands; eating foods exposed to dust; and inhaling and ingesting airborne dusts. In African cities and villages, preschool age children often accompany their mothers to work at roadside stands and stalls, or shops in market places. The conditions of hygiene in these settings are often poor and also dusty (Nriagu, 1991).

Von Schirnding and coauthors (1991) stated that social factors were important in influencing children's blood lead levels, including socioeconomic status (for example, the relative level of affluence of the family and the educational level of the child's parents) and other factors relating to family structure (for example, single-parent families, number of siblings) as well as occupation.

Studies in other parts of the world have found blood lead levels to be correlated directly or indirectly with socioeconomic status. In the USA, for example, low socioeconomic groups have been found to have higher blood lead levels than higher socioeconomic groups (Mahaffey et al., 1982), but other relationships have been seen elsewhere, depending on the prevailing forms of exposure.

Current national policy

Given the evidence from various studies of increased exposure to lead among large numbers of South African children, the absence of a national childhood lead surveillance program is a particular concern. Under the umbrella of occupational health and safety legislation, lead standards are in place for workers, and new lead regulations for the occupational setting have recently been presented for public comment. No similar provisions exist, however, in respect to children.

Until the 1980s, the maximum lead content in gasoline equaled 0.836 g/liter, but was subsequently reduced to 0.6 g/liter, and yet again to the current maximum permissible concentration of 0.4 g/liter. In 1996, unleaded gasoline was made available. However, despite an initial tax differential to encourage the use of unleaded gasoline, the transition to its use has been slow, and leaded gasoline remains the predominant fuel used in the country. The recent announcement that lead is to be phased out of gasoline in South Africa by 2006 has been widely welcomed. In the interim, however, the addition of methylcyclopentadienyl manganese tricarbonyl (MMT) has commenced in South Africa.

Since tetraethyl lead is being phased out of gasoline, MMT is being used as a replacement or additive to unleaded gasoline. In an internal combustion engine, MMT burns to form various carbon compounds. Some of these compounds have been shown to be toxic in high concentrations and are expected to cause adverse health effects at low concentrations, particularly if the fumes are inhaled.

During the 1970s, a voluntary agreement was reached with the paint industry to limit the lead content of paint in South Africa. There is ongoing concern, however, about the potential for children to be exposed to lead in settings where leaded paint is peeling or flaking from old school buildings or housing.

Recognizing the health threat, most developed countries have reduced the lead content of gasoline over the past decade. Unleaded gasoline has been introduced in most Latin American countries, Malaysia, Singapore, Taiwan, and the Republic of Korea, although in most cities of the developing world ambient air lead levels exceeded the health standard of 1 microgram per cubic meter in the 1980s (Nriagu, 1991). The announcement that lead will be phased out of gasoline in South Africa by 2006 comes more than two decades after this step was taken in the USA.

Addressing childhood lead exposure in South Africa

Results of studies of childhood and fetal blood lead levels undertaken in various parts of the country over the past two decades clearly demonstrate that childhood lead exposure continues to be a serious health threat in South Africa. South Africa is moving rapidly towards the widespread use of lead-free gasoline. Currently it is estimated that only around 10% of gasoline purchased in South Africa is lead-free. Programs need to be developed to identify and reduce hazards to child health from peeling or flaking of old paint from housing or schools. Attention also needs to be given to lead in paints used on surfaces that children are likely to chew, especially children's toys.

A national lead surveillance program would help to identify the key sources, mechanisms of exposure, and other risk factors for elevated blood lead levels among children, infants, and the developing fetus. Such a surveillance program should include aspects related to fetal and childhood blood lead burdens, and the lead content of soil, dust, air, paint/pigments, water, and food. Developing mechanisms to limit exposure to lead in the environment and food is likely to be particularly challenging. Children could be screened for lead exposure during clinic visits beginning at 6 to 9 months of age, and continuing periodically through the age of 6 years. The American Academy of Pediatrics recommends blood lead testing at 12 and 24 months of age.

A major and urgent educational effort is needed to improve awareness of the hazards of lead exposure among the general public and health personnel.

Capacity-building and research through the BNC

Working through the BNC, South Africa proposed to include environmental health for collaboration with its U.S. federal partners, including the Agency for Toxic Substances and Disease Registry. This may be a mechanism for the South African government to build capacity through training health professionals in lead exposure prevention and management. Emphases on training and skills development of health professionals are key. The binational agreement calls for collaboration and cooperation with the United States in the following areas: promoting sound scientific research and monitoring; ensuring widespread dissemination of the results of research; ensuring access to information; encouraging individuals and the communication media to act on the basis of sound science; and integrating knowledge of the environment at all levels of the formalized education system to ensure that all members of the population understand how to avoid the sources of environmental contaminants and prevent exposure to lead and other pollutants.

Discussion

South Africa is experiencing urbanization, and movement to cities has increased people's level of exposure to lead, a pervasive environmental toxicant. Studies have shown that children living in urban areas have significantly elevated blood lead levels. These levels are high compared with those of their counterparts in developed countries. Growing concerns about the health effects of low-level lead exposure and its potential public health impact have prompted the South African government to take actions.

The elevated blood lead levels in children in South Africa suggest that prevention strategies are needed to identify high-risk children and to reduce their body's lead burden and subsequent risk of exposure. International guidelines suggest blood lead levels of 10 μg/dl or higher warrant action to reduce exposure.

In view of emerging evidence linking lead at increasingly lower levels to adverse effects in children, the South African government is working with the U.S. Department of Health and Human Services to develop contacts and research capacity for studies of health effects of lead and other pollution exposures. The South African government, working through the Binational Commission, proposes to address the deficiencies that exist in the South African government regarding its response to environmental toxicants. To address these weaknesses, the agreement calls for a plan to improve the scientific basis for making decisions on environmental issues. The proposal outlined in the MOU suggests integrated activities based on research; ongoing assessments of environmental knowledge and its implications; information management and communication; and education and training. These collaborative research programs may provide new knowledge to assist the South African government in taking the necessary actions to reduce lead exposure among vulnerable groups.

Conclusion

Environmental exposure to lead remains a prominent, preventable environmental public health concern in the developing world. The problem is of particular concern in developing countries because 1) sources of exposure remain; 2) no surveillance programs are in place; and 3) there is a lack of adequately trained physicians and other health care providers to identify and address these health issues. In light of the recent evidence linking increasingly lower blood lead levels to adverse health effects, including neurobehavioral performance in children, South Africa is proactively moving forward to develop international and regional relationships to help reduce lead exposure.

References

Agency for Toxic Substances and Disease Registry. (ATSDR) Toxicological profile for lead. U.S. Department of Health and Human Services, Atlanta, Georgia (1999).

Annest, J. L., Pirkle, J. L., Matuc, D., Neese, J. W., Bayse, D. D. and Kovar, M. G.: Chronological trend in blood lead levels between 1976 and 1980. N Engl J Med 308, 1373–1377 (1983).

Brody, D. J., Pirkle, J. L., Kramer, R. A., et al.: Blood lead levels in the US population. Phase 1 of the Third National Health and Nutrition Examination Survey. JAMA 272, 277–283 (1994).

Cowie, C., Black, D. and Fraser, I.: Blood lead levels in preschool children in eastern Sydney. Aust N Z J Public Health; 21, 755–761 (1997).

Emory, E., Pattillo, R., Archibold, E., Bayorh, M. and Sung, F.: Neurobehavioral effects of low-level lead exposure in human neonates. Am J Obstet Gynecol 181, S2–S11 (1999).

Falk, H.: International environmental health for the pediatrician: case study of lead poisoning. Pediatrics. In Press 2002.

Kibel, M. A., von Schirnding, Y. E. R., Mathee, A. and Dempster, W.: Blood-lead levels of children in the Western Cape. Childhood 1, 220–224 (1993).

Mathee, A., von Schirnding, Y. E. R., Ismail, A. and Huntley, R.: Surveys of blood lead burdens among school children and newborns in Greater Johannesburg, Urbanisation and Health Newsletter 29, 43–49 (1996).

Mahaffey, K. R., Annest, J. L., Roberts, J. and Murphy, R. S.: National estimates of blood lead levels: United States, N Engl J Med 307, 573–579 (1982).

NAS. Lead in the human environment. Environmental Studies Board, National Academy of Sciences, Washington, D.C. (1980).

Nriagu, J. O.: Review. Toxic metal pollution in Africa. Sci Total Environ. 121, 1–37 (1991).

Schutz, A., Attewell, R. and Skerfving, S.: Decreasing blood lead in Swiss children 1978–1988. Arch Environ Health 44, 391–394 (1989).

Statistics South Africa.. Census in Brief Report No. 1, 03-01-11[1996] (1998).

Tong, S., von Schirnding, Y. E. R. and Prapamontol, T.: Environmental lead exposure: a public health problem of global dimensions. Bull World Health Organ 78(9), 1068–77 (2000).

von Schirnding, Y. E. R., Bradshaw, D. and Fuggle, R. F.: Blood lead levels in South African inner city children. Environ Health Perspect 94, 125–130 (1991).

von Schirnding, Y. E. R., Mathee, A., Robertson, P., Strauss, N. and Kibel, M.: Distribution of blood lead levels in school children in selected Cape Peninsula suburbs subsequent to reductions in petrol lead. S Afr Med J 91(10), 870–2 (2001).