LEAD POISONING AMONG CHILDREN FROM SANTO AMARO, BRAZIL[1]

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A survey designed to detect lead poisoning was carried out among 693 children living near a lead smelter in Santo Amaro, Brazil. Very high levels of zinc protoporphyrin and lead were detected in the children's blood, revealing serious lead poisoning and dangerous levels of environmental contamination.

Introduction

Santo Amaro is a city in the state of Bahia in Northeast Brazil; according to the 1980 National Census *(1)* Santo Amaro then had a population of 29,627 inhabitants. For hundreds of years, sugar cane has been the area's main cash crop, but the city's strategic location in the inner part of Todos os Santos Bay (Figure 1) has also favored a flourishing maritime trade. In recent decades, the rapid industrialization of nearby areas and the extensive use of highways for transportation of goods has produced a negative impact upon the economic life of the city. (Fishing, once an important economic subsistence activity, has been declining, for example.) These circumstances have contributed to making a large number of people unemployed, although local conditions have also attracted some industries to the area, mainly because of cheap and abundant labor.

Over the past three decades, living conditions in northeastern Bahia's rural areas have been gradually deteriorating. Consequently, large numbers of rural people have migrated to the cities; and the industries established in Santo Amaro, including a lead smelter, have served as magnets for immigrants seeking work. Consequently, newly arrived families have tended to occupy areas near such industries that have also tended to be the worst residential areas in the city. As a result of this process, a large population currently lives around the Santo Amaro lead smelter, most of this population consisting of the members and immediate families of the smelter's own work force.

This primary lead smelter, a subsidiary of the multinational company Penarroya, has been operating on the outskirts of Santo Amaro since 1960. The smelter has employed about 260 workers and has produced about 32,000 tons of lead bars per year *(2)*. Since its inception, however, the smelter has given rise to complaints from local residents concerning the death of cattle, horses, and birds as well as loss of garden crops. It is known that at least 250 tons of cadmium have been dumped directly into the Subae River, which crosses the city, and that another 150 tons have been released to the air. The total lead burden is difficult to estimate, but the contamination of sediments and fauna by heavy metals has been reviewed by Souza et al. *(3)*. The toxic effects of environmental lead and cadmium on the health of the local inhabitants have been described elsewhere *(4, 5, 6, 7)*. The aim of the study reported here was to determine the prevalence of lead poisoning among the children in

[1]This article will also be published in Portuguese in the *Boletín de la Oficina Sanitaria Panamericana,* 1986.

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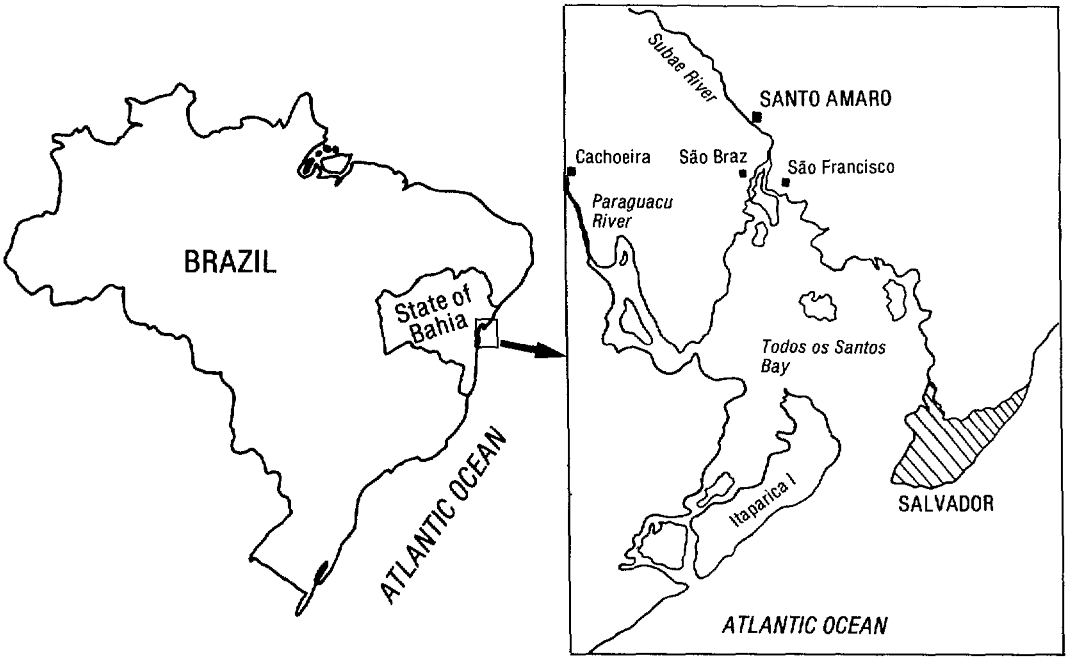
Figure 1. A map of Brazil showing the state of Bahia and the location of Santo Amaro.



Santo Amaro and to describe the major risk factors involved.

Materials and Methods

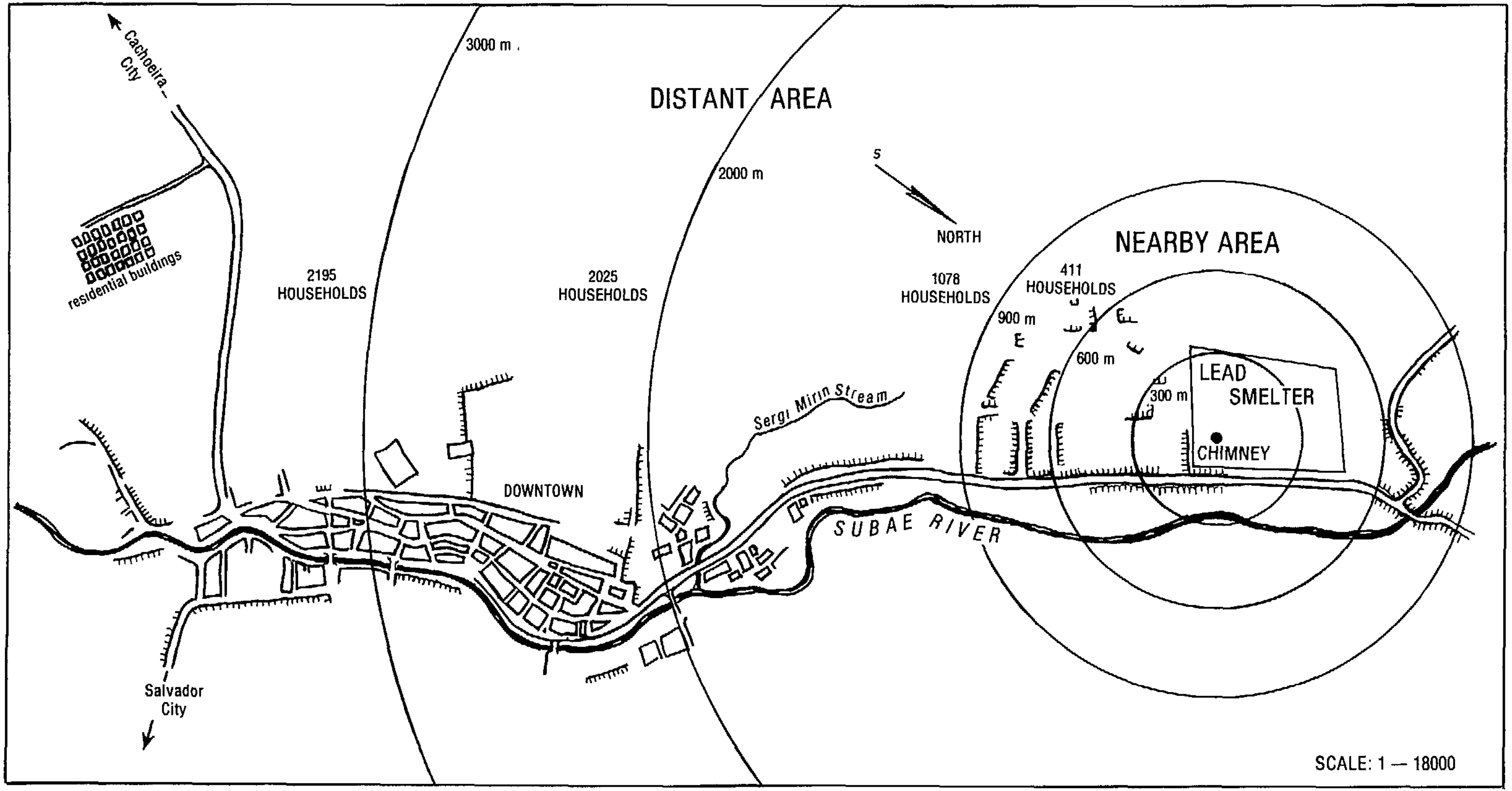
For purposes of this study, a prevalence survey of lead poisoning among children one to nine years old who were living in the urban area of Santo Amaro was carried out in the third quarter of 1980. The city was divided into two survey zones, one zero to 900 meters from the smelter chimney (Figure 2) and the other more distant (901 to 5,000 meters from the chimney). Detailed city maps were provided by the local prefecture.

The zinc protoporphyrin (ZPP) concentration in the blood of 592 of the 648 children living in the nearby area was determined. In the distant area, a random sample, stratified by three subareas (at distances of 901-2,000 meters, 2,001-3,000 meters, and 3,001-5,000 meters from the chimney) *(8)* was obtained. A pilot study carried out among 29 children one to nine years old provided some basic information for the definitive sampling, during which samples were obtained from 101 children in 101 different households, out of the distant area's total of 5,298 households.

The adults responsible for each child were interviewed in the home by two physicians and two medical students. Mothers were asked for information about the child; fathers were asked about their monthly earnings and their occupational and migratory histories.

The presence of visible smelter dross in the home environment of each child was noted. This dross, a by-product of lead ore processing, has a characteristic appearance. It was given freely by the lead smelter to the population and was extensively used by the residents for paving back yards, gardens, streets, and other public places. The smelter dross contains from 1% to 3% lead *(2)*; its solubility in water is negligible but in acidic media is very high *(9)*. The relationship

Figure 2. A map of Santo Amaro showing the "nearby" study area (within 900 meters of the smelter chimney), the "distant" study area (901-5,000 meters from the smelter chimney), and the numbers of households within 900, 2,000, 3,000, and 5,000 meters of the chimney.



of each household to the asphalt roads on which trucks transported lead ore was also noted. The children were classified into three racial groups based on skin color *(10)*, these being "light," "medium," and "dark."

Blood was obtained by venipuncture from children in the area near the chimney, and by finger-prick and collection in capillary tubes from those in the distant area. The ZPP concentration in whole blood was determined with a hematofluorimeter manufactured by Buchler Instruments, using their instructions *(11)*. The lead in the blood samples (PbB) was analyzed by flameless atomic absorption, using a modification of the method described by Fernandez *(12)*. Serum iron (FeS) and total iron-binding capacity (TIBC) were determined photocolorimetrically, using the Harleco method *(13)*. The transferrin saturation (TS) index was calculated as follows:

$$FeS \div TIBC \times 100 = TS.$$

PbB and FeS determinations were made only for study children in the nearby area; the numbers of analyses were 555 and 512, respectively. ZPP and PbB concentrations were expressed in "international system" (SI) units *(14)*. (The factor needed to convert ZPP μmol/l to μg/dl is 57.14, and that needed to convert PbB μmol/l to μg/dl is 20.83.) A set of statistical computer programs developed by Nie et al. *(15)* was used for data analysis. The distributions of ZPP and of fathers' earnings were very skewed, and were therefore logarithmically transformed. Mean ZPP levels were always expressed as the geometric mean (GM) and its standard deviation (GSD).

Results

Table 1 shows the mean (GM) levels of ZPP in terms of the distance from the child's home to the smelter chimney. The geometric mean and the geometric standard deviation of the ZPP levels were 1.16 and 2.31 μmol/l, respectively, with the observed range of individual ZPP levels extending from 0.07 to 14.45 μmol/l. Levels greater than 1.00 μmol/l and 5.00 μmol/l were found in 58.5% and 3.2% of the study children, respectively.

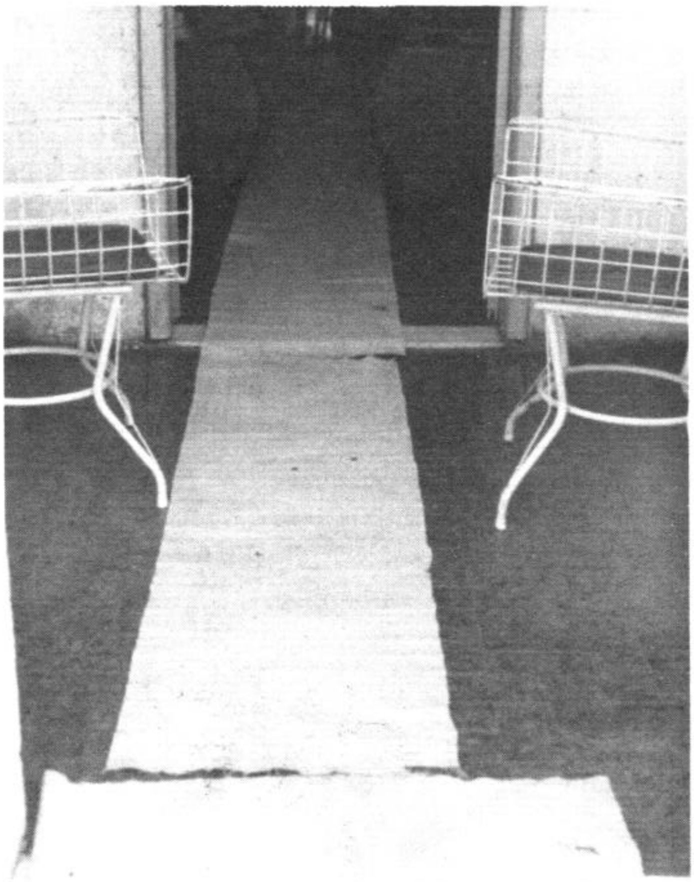
Like ZPP levels, the PbB levels observed in children from the nearby area showed a marked tendency to decrease with increasing distance from the smelter chimney (Table 2). Overall, the mean PbB level was 2.84 μmol/l, with a standard deviation of 1.20; the actual values obtained ranged from 0.77 to 7.50 μmol/l. Seventy-five per cent of the study children tested were found to have PbB levels greater than 2.00 μmol/l. The simple regression coefficients between logZPP and PbB and between logZPP and the transferrin saturation index (TS) were $r = 0.54$ ($P < 0.00001$) and $r = -0.13$ ($P < 0.005$), respectively. The partial correlation coefficient between logZPP and PbB, controlling for the effect of TS, was 0.55; and that between logZPP and TS, controlling for the effect of PbB, was -0.17.

Table 1. Zinc protoporphyrin (ZPP) levels found in 693 study children living at different distances from the smelter chimney. The levels shown for each group are the geometric mean (GM) and the geometric standard deviation (GSD).

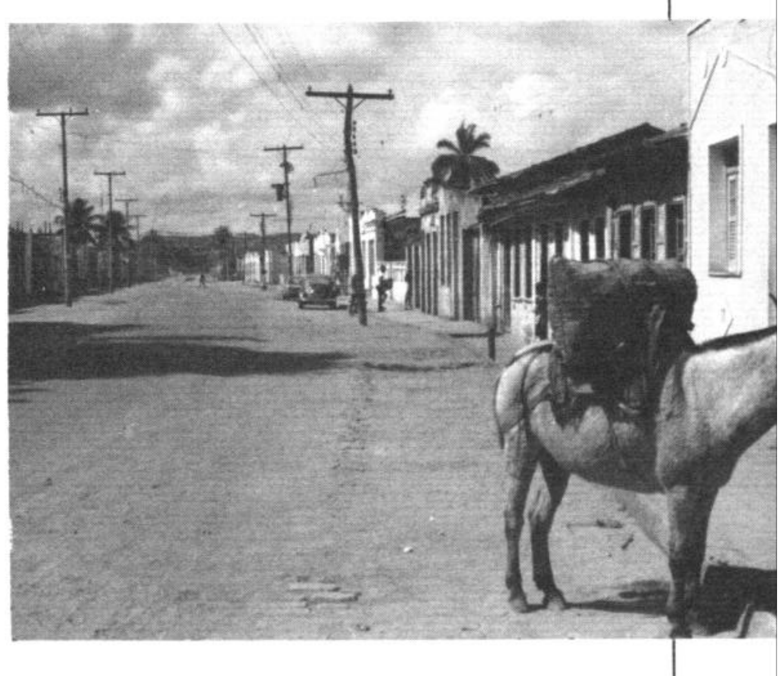
Distance of home from smelter chimney	No of children	ZPP levels (μmol/l)	
		GM	GSD
0-300 m	73	2.83	1.85
301-600 m	170	1.47	2.41
601-900 m	349	1.03	2.02
901-2,000 m	21	0.93	1.86
2,001-3,000 m	38	0.74	1.84
3,001-5,000 m	42	0.45	1.74
Total	693	1.16	2.31

Table 2. Blood lead (PbB) levels found in 555 study children living within 900 meters of the smelter chimney, by 300-meter intervals. The figures shown for each group are the arithmetic mean ($\bar{X}$) and standard deviation (SD).

Distance of home from smelter chimney	No. of children	PbB levels (μmol/l)	
		$\bar{X}$	SD
0-300 m	68	4.19	1.44
301-600 m	154	2.91	1.14
601-900 m	333	2.53	0.93
Total	555	2.84	1.20



Photographs from Santo Amaro showing (1) old filter material given away by the smelter and used as carpets; (2) smelter dross along a roadside, free for the taking; and (3) the road referred to in the text that was used by trucks transporting smelter ore. Most homes in the latter picture are within 600 meters of the smelter chimney.



As Table 3 shows, children one and two years old had the highest mean ZPP levels. Also, the geometric mean ZPP levels of the study children who had migrant fathers (GM of 1.12 μmol/l with a GSD of ±2.32 μmol/l) was significantly lower (P<0.05) than that of the study children whose fathers had never left Santo Amaro (GM of 1.34 μmol/l with a GSD of ±2.24 μmol/l). In addition, as Table 4 shows, children who had lived for six months or less in the area within 900 meters of the smelter chimney had a lower geometric mean ZPP than those who had lived there longer. This tendency was evident only among children in the "nearby" area rather than the "distant" area (see Figure 2).

Regarding racial groupings, the data in Table 5 indicate that the study children classified as being "dark" had higher mean ZPP levels than did the children classified as being "medium" or "light." Also, children in both the "distant" and "nearby" areas whose fathers were lead workers were found to have significantly higher ZPP levels than children in the same area whose fathers pursued other types of work (Table 6). And children whose homes were situated along roads on which the smelter ore was transported were also found to have significantly higher ZPP levels (P<0.00001) than other study children (Table 7). This last difference was evident mainly among children living in the "nearby" area. The presence of visible smelter dross in a child's home environment was also associated with significantly higher mean ZPP levels when the sample was analyzed in total (P<0.0005) but not when it was analyzed by area (Table 8).

Table 3. Zinc protoporphyrin (ZPP) levels in the 693 study children, by age group.

Children's age (in years)	No. of children	ZPP levels (μmol/l)	
		GM	GSD
1	70	1.90	2.26
2	100	1.48	2.07
3	95	1.17	2.19
4	78	0.96	2.30
5	71	1.04	2.22
6	68	1.15	2.20
7	74	1.16	2.08
8	63	0.78	2.39
9	74	1.01	2.53
Total	693	1.16	2.31

Table 5. Zinc protoporphyrin (ZPP) levels among the study children, by racial classification.

Racial classification	No. of children	ZPP levels (μmol/l)	
		GM	GSD
Light	105	0.95	2.24
Medium	211	1.03	2.23
Dark	373	1.32	2.33
Total	689	1.16	2.31

Table 4. Zinc protoporphyrin (ZPP) levels found in 625 of the study children grouped according to whether they had lived in their area of residence for more or less than six months, and whether their home was less than 900 meters or between 901 and 5,000 meters from the smelter chimney.

Distance of home from smelter chimney	Length of residence in area (in months)	No. of children	ZPP levels (μmol/l)		P
			GM	GSD	
Nearby	≤6	52	0.62	2.81	<0.00001
(0-900 m)	>6	534	1.39	2.14	
Distant	≤6	7	0.98	2.12	>0.05
(901-5,000 m)	>6	91	0.62	1.91	
Total	≤6	59	0.65	2.69	<0.00001
(0-5,000 m)	>6	625	1.23	2.23	

Table 6. Zinc protoporphyrin (ZPP) levels among study children whose fathers were lead workers, as compared to those whose fathers were not.

Distance of home from smelter chimney	Child of leadworker	No. of children	ZPP levels (μmol/l)		P
			GM	GSD	
Nearby	Yes	130	1.71	2.12	<0.00001
(0-900 m)	No	457	1.19	2.28	
Distant	Yes	3	1.76	1.26	<0.005
(901-5,000 m)	No	96	0,60	1.89	
Total	Yes	133	1.71	2.11	<0.00001
(0-5,000 m)	No	553	1.06	2.30	

Table 7. Zinc protoporphyrin (ZPP) levels among the 693 study children, grouped according to whether their homes were located along roads used to transport smelter ore.

Distance of home from smelter chimney	Home along road used to transport smelter ore	No. of children	ZPP levels (μmol/l)		P
			GM	GSD	
Nearby	Yes	192	1.64	2.20	<0.00001
(0-900 m)	No	400	1.06	2.24	
Distant	Yes	19	0.69	1.69	>0.05
(901-5,000 m)	No	82	0.62	1.33	
Total	Yes	212	1.52	2.25	<0.00001
(0-5,000 m)	No	481	1.03	2.27	

Table 8. Zinc protoporphyrin (ZPP) levels among the 693 study children, grouped according to whether smelter dross was observed in the home environment.

Distance of home from smelter chimney	Smelter dross present in home environment	No. of children	ZPP levels (μmol/l)		P
			GM	GSD	
Nearby	Yes	258	1.38	2.13	<0.05
(0-900 m)	No	334	1.23	2.36	
Distant	Yes	14	0.67	1.97	>0.05
(901-5,000 m)	No	87	0.62	1.92	
Total	Yes	272	1.33	2.16	<0.0005
(0-5,000 m)	No	421	1.07	2.38	

Application of a stepwise multiple regression equation (Table 9) showed that the variation toward higher logZPP levels was significantly associated ($P<0.05$ or less) with the following: decreasing distance from the child's home to the smelter chimney; a residence time in Santo Amaro greater than six months; decreasing age; location of the home along a road used for transporting smelter ore; classification in the "dark" racial group; and having a father who is a lead worker. The slopes of certain other variables (smelter dross observed in the child's home, having a migrant father, the log of the father's monthly income, and classification in the "medium" racial group) were not statistically significant at the 5% probability level. The codes used for "dummy" variables are shown in the footnotes of Table 9.

Table 9. Results obtained by applying a multiple regression equation having logZPP (μmol/l) as the dependent variable for 645 children from Santo Amaro City. The numbers in the columns are regression coefficients (B) and standard errors (SE_B).

Independent variable	B	SE_B
Distance (0.1 km)	-0.1429[a]	0.0137
Residence time (months)[c]	0.3618[a]	0.0436
Age (years)	-0.0417[a]	0.0046
Household localization[c]	0.1272[a]	0.0304
Racial group "dark"[c]	0.1238[a]	0.0360
Child of lead worker[c]	0.0704[b]	0.0293
Smelter dross[c]	0.0330	0.0266
Migrant father[c]	-0.0294	0.0292
Racial group "medium"[c]	0.0191	0.0374
Log of father's monthly earnings (in Cruzeiros)	0.0286	0.0352
Intercept	0.3627	–

Note: $R^2 = 36\%$.
[a]$P<0.05$.
[b]$P<0.005$.
[c]Codes used for "dummy" variables:
Residence time in the area: ≤6 months = 0; >6 months = 1.
Home located alongside a road used for smelter ore transportation: No = 0; Yes = 1.
Racial group: Light = 0; Medium = 1; Dark = 1.
Child of lead worker: No = 0; Yes = 1.
Smelter dross visible in child's peridomiciliary environment: No = 0; Yes = 1.
Migrant father: No = 0; Yes = 1.

Discussion and Conclusions

Increased ZPP levels are commonly found in iron-deficient subjects *(16, 17,18)*. However, in our data the partial correlation coefficient between logZPP and PbB, controlling for the effect of TS ($r = 0.55$), was higher than that observed for logZPP and TS, controlling for PbB ($r = -0.17$). This suggests that the variation in logZPP levels in the Santo Amaro study children was much more strongly associated with the toxic effects of lead than with iron deficiency.

The simple correlation coefficient between logZPP and PbB was lower than those that have been reported by other authors *(19, 20, 21)*. This could be explained by disproportionately high PbB levels caused by a recent, intense exposure to lead. That is because the levels of lead in blood increase rapidly following exposure *(18)*, but the levels of ZPP in blood take about 90 days to increase after exposure *(21)*. Exposure to lead had increased very recently in Santo Amaro because used filters, containing high quantities of particulate lead, were taken from the smelter by the lead workers for use in their homes *(6)*. Almost 500 pieces of thick cloth, which were the disposable part of an antipollution device, were taken away from the smelter. They were used as carpets, cleaning cloths, and bedspreads and also had other domestic and personal uses.

The geometric mean ZPP level in the children from Santo Amaro was 1.29 μmol/l (GSD ±2.29 μmol/l) with a range of 0.07 to 14.45 μmol/l. In the largest screening program for lead poisoning in children ever conducted, the U.S. Centers for Disease Control *(22)* considered that the ZPP level should not exceed 0.94 μmol/l (54 μg/dl). Values above 4.81 μmol/l (275 μg/dl) are considered extremely high and signify that the child is at high risk of presenting with clinical evidence of lead poisoning.

PbB levels among the children from Santo Amaro were also very high. As Table 2 shows, the EEC *(23)* reference level (wherein 98% of the sample has PbB levels below 35 μg/dl or 1.68 μmol/l) was far exceeded.

It was very difficult to single out risk factors for lead poisoning among the Santo Amaro study children in order to assess those factors separately. However, Tables 3 to 8 present the data obtained when we tried to show the separate effects of some risk factors on ZPP levels. In addition, a global view of the relative importance of each factor was provided by the multiple regression technique (Table 9). It should be noted, however, that only 36% of the variation in logZPP levels could be explained by the equation. Other variables beyond the strictly biological (age, racial group "dark") also appeared relevant.

The pathogenicity of the contaminated environment was revealed by the effects of distance, residence time, and home location. More specifically, the regression coefficient found for the variable "residence time" (Table 9) shows that children who had lived in the area involved for more than six months had a predicted mean logZPP level 36% higher than children who had lived in the area for six months or less. Also, the multiple regression model predicted an approximate 13% increase in the mean logZPP level of children who lived in homes located along the roads used for the transportation of lead ore. This increase in logZPP levels is probably associated with the inhalation of particulate lead resuspended by motor vehicles that travel on the dry, dusty, asphalt roads.

In addition, children of lead workers from Santo Amaro were found to have a mean logZPP level 7% higher than children whose fathers had other jobs, after controlling for the other variables listed in Table 9. In general, being a child of a lead worker is known to be an important risk factor for lead poisoning *(24, 25, 26)*. For the children from Santo Amaro, this risk was probably increased after the contaminated filters were taken home.

As soon as the laboratory results, which indicated a serious epidemic of lead poisoning, were available, meetings were held with the population and with the smelter management in order to deal with the problem. A written report was given to the state health authorities suggesting measures that might be taken to minimize the problem. All the suggestions were promptly accepted by the state government, and legal instructions were put forward. The lead smelter had to pay all expenses involved and also had to shoulder responsibility for the health of the children and the measures adopted to control the environmental pollution *(27)*. These pollution control measures implied a 50% decrease in lead production by the smelter.

Overall, this episode produced a growing concern for environmental quality on the part of a population that was weakly represented in the society at large but that organized itself and pressed the state for concrete measures against pollution. This manifestation of social stress resulted in the creation of a government organ, subordinated to the State Department of Health, to deal with specific problems of environmental health. Its first target has been the lead pollution in Santo Amaro *(9)*.

The case of lead pollution in Santo Amaro also illustrates the consequences of exporting hazardous factories and technologies from developed to developing countries *(28)*. In the former, society has more concern with safety at work and with environmental quality. In the latter, labor is cheap, and laws to protect the environment are few and more permissive. Multinational corporations are making profits out of this worldwide division of labor *(29)*. The intense industrial growth pursued by the economic policies of developing countries permits obsolete and hazardous technologies to be employed, and environmental quality and safety tend to be considered secondary issues *(30)*. Within this context, it is to be expected that industrial residues will disturb the equilibrium of the ecosystem and may harm the health of populations living near the factories involved.

SUMMARY

Since 1960, a primary lead smelter has been operating on the outskirts of Santo Amaro, Brazil, a small city in the northeastern state of Bahia. Many local families, including the families of many lead workers, have lived close to the plant.

In 1980 a survey was conducted of children living near the smelter, especially those whose homes were 900 meters or less from the smelter's chimney, in order to determine whether their health was being endangered by lead contamination. This survey found unusually high levels of zinc protoporphyrin and lead in the study children's blood, as well as statistically significant associations between zinc protoporphyrin levels and the following variables: the distance between the child's home and the smelter chimney; the family's length of residence in the area; whether or not the child's home was on a road used to transport lead ore; the child's racial classification; the child's age; and whether or not the father was a lead worker.

As a result of these findings, ensuing public concern, and presentation of a written report to the state health authorities, major pollution control measures were adopted. These measures, which implied a 50% decrease in lead production by the smelter, were paid for by the smelter, which also had to shoulder responsibility for the affected children's health.

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