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Environmental health aspects of lead

Die gesundheitlichen Aspekte der Umweltverschmutzung durch Blei

Les problèmes sanitaires posés par le plomb présent dans l'environnement

THE UPTAKE AND EXCRETION BY CHILDREN OF LEAD AND OTHER CONTAMINANTS

ALEXANDER F.W., DELVES H.T., CLAYTON B.E.

Hospital for Sick Children
LONDON, UNITED KINGDOM

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Summary

Balances have been performed for the contaminants lead, strontium and cadmium upon eight healthy children at home and six children with inborn errors of metabolism in hospital. The balances were for three days and included the use of metal-free diapers where appropriate. The concentration of metals in the samples was determined by atomic absorption spectrophotometry after suitable preparation.

The results showed that there is a significantly greater loss of strontium by the children receiving synthetic diets which is probably related to the lower concentration of phosphorus in these diets.

The uptake of cadmium was found to depend more upon the type than upon the amount of diet consumed. The daily intake of cadmium per kg body weight was considerably less than previous figures and all the children were consistently in negative balance.

The mean daily intake of lead in both groups of children was lower than previously recorded figures. The normal group< however, absorbed a mean value of 50% and retained a mean value of 18% of the dietary intake. The children on synthetic diets showed a significantly lower percentage absorption. Nevertheless it is suggested that the upper safety limits for the concentration of lead in food consumed by children is still too high on the basis of these results.

Introduction

It has been suggested by a number of workers that children, and the young of any given species are more prone to lead poisoning than adults (Berry, 1966: Clegg & Rylands, 1966; Min.Agric.Fish & Food, 1959). This tendency may be the result of increased ingestion from oral exploration of the environment (Barltrop, 1966) and to an increased susceptibility of the young animal to the presence of inorganic ledd (Pentschew and Garro, 1966). Other contaminants may also play a part in human diseases. Schroeder (1967) reported that the addition of 5 ppm cadmium to the drinking water of thriving cadmium-free rats, lead to the development of hypertension. This effect and the teratogenesis produced by feeding cadmium to pregnant golden hamsters (Ferm and Carpenter, 1967) were both alleviated by the administration of zinc. The fallout of ^{90}Sr from the stratosphere following atomic explosions aroused interest in strontium metabolism. This isotope has a half life of 28 years and the principal route for contamination is through vegetation (Arneil,1969). It has a similar metabolism to calcium and is a potential hazard to the bones of infants.

There are few reports of balances performed on infants and young children for trace metal contaminants. The concentration of lead in various foodstuffs has been measured by a number of workers (Kehoe et al., 1933: Kehole et al., 1940). Kehoe et al (1933) also measured the excretion of lead in urine and faeces by American children and by native Mexican Indian children for comparison. Kehoe (1964) and Bicknell et al. (1968) measured the urinary excretion of lead by normal children and suggested an upper limit of 80 µg/litre. Chisolm and Harrison (1956) and Barltrop and Killala (1967) reported a mean normal faecal lead excretion of 130 µg/24 hr.

Cavell and Widdowson (1964) performed 3-day balances on 10 full-term breast-fed, infants for cadmium. All ten infants absorbed cadmium from milk with a mean absorption of 48% and all but two were in positive cadmium balance with a mean retention of 20%.

Widdowson et al. (1960) measured the uptake and excretion of strontium by breast-fed and bottle-fed neonates. The results suggeted a preferential absorption of calcium instead of strontium and a preferential urinary excretion of strontium instead of calcium by the breast-fed children. This preferential excretion was later confirmed by Widdowson et al. 1963 who showed that it was reduced by the addition of phosphorus to the breast milk diet.

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We have performed 11 balance studies on 8 healthy children and 6 balances on children with inborn errors of metabolism.

Although the purpose of the work was to determine the requirements by children on synthetic diets for the essential minerals and trace elements, balances for the three contaminants cadmium, strontium and lead were included in this study. The balances were performed because of the paucity of data for children, to compare the balances of the contaminants with those of the essential elements, and also because they are implicated in the development of certain human diseases.

The collection of excreta in infants and young children during metabolic balances is difficult since they wear diapers and are so active. Previous workers have tackled the problem in different ways; Widdowson (1965) collected urine into polythene bags attached to the perineum, and used nylon diapers to collect the faeces. McCance et al. (1970) collected faeces into a stainless steel bowl after strapping the infant into a metabolic chair. These methods are limited to the examination of boys and there is a high risk of contamination. Also Rose (1960) and Millard (1970) have shown that immobilisation leads to an increased excretion of calcium and although it is not known whether other minerals are affected similarly, immobilisation should be avoided.

We have developed a method for collecting excreta which is extremely successful, and avoids immobilisation, the use of any apparatus and can be used as easily for girls as for boys.

This method employs disposable paper diapers ("Sofdown" diapers) held in place by a specially cut plastic "tie-pant" (both made by Lewis Woolf Ltd., U.K.). Neither of these could be used as supplied since they contained appreciable amounts of the metals being studied. The diapers were rendered 'metal-free' by a simple process involving washing with an aqueous solution of ethylene diamine tetra-acetic acid (disodium salt) and then with water. They were then dried in an oven at 80°C. The diaper was altered very little by this process. It remained intact, white and the absorbancy for water was reduced by 25% (Alexander and Delves, submitted for publication).

Balance Technique

1. Subjects

Group 1 - a control group of eight healthy children whose ages ranged from 3 months to 8½ years, 5 of whom were living at one or other of our homes and the other 3 in an institution; all were on a free diet. The youngest of this group was breast-fed at the time of testing.

Group 2 - consisted of six patients with inborn errors of metabolism living in a hospital environment on synthetic diets

(ages 3 weeks to 8½ years).

2. Method Exact duplicate diets, and urine were collected for 3 x 24 hr periods. The faeces were collected between carmine and Edicol blue markers on to the deionised diapers which were changed as required. The faeces were separated from the diaper by removing the non-wettable cover and transferring to a polythene container. The soiled cover was washed with water and the washings added to the faeces. The diaper was washed with a 1% hydrochloric acid solution to remove the urine and to elute the trace metals from the diaper.

The total 3-day diet and faecal collection were homogenised using a nylon-coated homogeniser and weighed portions were transferred to quartz beakers, as were measured volumes of the urine eluate. The samples were then dried on a sand bath at 100°C, ashed in a muffle furnace overnight at 550°C, and the residues dissolved in concentrated HCl and made up to a known volume. The concentrations of cadmium, strontium and lead in the samples were measured by atomic absorption spectroscopy using appropriate aqueous standards (Alexander and Delves, in press).

Results

Figures 1, 3 and 5 show the daily intake by the two groups of children of lead, strontium and cadmium plotted against weight. Figures 2, 4 and 6 represent the daily intake and excretion per kg body weight of the 3 metals. The healthy children are represented by the open circles, the children with inborn errors of metabolism by the closed circles. The solid regression lines in Figures 1, 3 and 5 apply to the healthy children (Group 1), the broken lines apply to the patients on synthetic diets (Group 2). The mean daily intake and excretion of lead, strontium and cadmium are listed in Table I together with values for nitrogen for comparison.

The daily intake of lead increases with weight from 40 µg in a breast-fed infant to 210 µg in an 8½-year-old on a free diet (Figure 1). The daily intake of lead by the children in Group 2 of 90 µg at 1 month to 240 µg at 8½ years does not differ significantly from that by Group 1.

The mean total daily intake per kg is greater for the children in Group 2 who also have a greater mean daily excretion than those in Group 1 (Table I), but again this difference is not statistically significant. The absorption of lead by the healthy children (Group 1) expressed as a percentage of the intake was 53%, whereas that by the children in Group 2 was 24%. This difference is significant ($p<0.01$). The mean daily retentions of 2.03 µg/kg by the children in Group 1 and of 1.48 µg/kg by Group 2 were not significantly different.

The daily intake of strontium by the breast-fed normal child was 100 µg and this rose to 700 µg at 8½ years (Figure 3). The intakes by the children in Group 2 did not differ significantly from the normals although they tended to be higher in the older age group. The mean total daily excretion of strontium by the children in Group 2 was higher than that of Group 1 because of a greater faecal excretion. This lead to a significantly greater loss of strontium by the children in Group 2. The variation of the intake of cadmium with weight by the normal children (Figure 5) shows a much wider scatter than that of the other two metals, (correlation coefficient, 0.38). The daily intake by the children in Group 2 does not differ significantly from the normal Group 1 children but follows the increase in weight more linearly (correlation coefficient 0.91). The mean faecal excretion of cadmium by the children in Group 2 was 0.94 µg/kg/day which was significantly greater ($p<0.0025$) than that of the normal group (0.50 µg/kg/day. This lead to a mean percentage absorption of cadmium by the children in Group 2 of 19% which is significantly lower than the normal absorption of 49%. However, the comparison between the mean retentions by the two groups (Figure 6) reveals a significantly greater loss of cadmium by the normal (Group 1) as opposed to the Group 2 children ($p<0.005$).

The intake and excretion of nitrogen by both groups of children were comparable (Table I). There was no difference between the mean percentage absorption of the two groups (90%, Group 1; 93%, Group 2) and although the mean percentage retention of nitrogen by the children in Group 2 was nearly twice that by the normal children, this was not a significant difference.

Discussion

The intake of 100 µg/day of strontium by the breast-fed 2-month-old child (Figure 3) is of the same order as that found by Widdowson et al. (1963) for breast-fed neonates. The significantly greater loss of strontium by the children in Group 2 as compared with the normal group needs an explanation. Widdowson et al. (1960; 1963) demonstrated that calcium is absorbed in preference to strontium but that the addition of phosphorus to the diet increases the absorption and retention of strontium and may act as the limiting factor in calcium absorption. We have measured both calcium and phosphorus uptakes and excretions in both groups (Alexander and Delves, in press). The calcium content of the diets of both groups is comparable, but the diets of Group 2 contains less phosphorus than the normal diet (mean calcium/phosphorus ratio, 1.14 for the Group 2 diet; 0.76 for the Group 1 (normal) diet. Our results, therefore, confirm the previous observations that reduction in phosphorus level in the diet leads to a

reduced absorption of strontium and a significantly greater loss of strontium from the body.

The intake of cadmium appears to depend more upon the type of diet consumed than upon the age and weight of the child; for example, the mixed diet of the 13-month-old normal child contains 21 µg/day; a second diet at the same age contained only 8 µg/day; a third diet for an 8½ year-old normal child contained 13 µg/day. This variation must depend upon environmental contamination of the differing diets and upon the different ways in which the food was prepared in the home. By contrast, the daily intake of cadmium by the children in Group 2 increased linearly with weight. These diets were very similar; were prepared in the hospital diet kitchen, and thus received the same degree of contamination.

The concentration of cadmium in the daily diets of both groups/kg body weight is approximately one-third of that found by Cawell and Widdowson (1964) in their study of breast-fed neonates. They also reported a mean daily retention of cadmium of 20%. In our study both groups of children are in strongly negative balance for cadmium (Table I). Although the mean daily fecal excretion by the children in Group 2 is greater than that of the normals in Group 1, the urinary excretion is very much smaller and there is thus a smaller mean daily loss of cadmium. We have shown in our study of zinc levels that the synthetic diets contained less than half the concentration of zinc in the normal diets (Alexander & Delves, submitted). Zinc and cadmium are adjacent elements in the periodic table and an interaction between the two has been shown by Schroeder (1967) and by Ferm and Carpenter, (1967). This competition between the two elements may explain the difference which we have observed.

The very low daily intake of lead by the normal breast-fed child (40 µg) has been noted before (Barltrop, 1969) and has been explained by a filter-mechanism in the lactating mammary gland.

The daily intake of lead, by both groups of children, increased linearly with age (Figure 1). This intake never reached the level of 300 µg per day reported by Kehoe (1961) as the mean daily intake of lead for normal American adults and the value presumed by Barltrop (1969) to be the maximum daily intake for children.

Kehoe (1961) showed that normal adults excreted a mean value of 300 µg daily in their faeces representing an absorption of lead of zero. In a second study he reports an absorption of 17% lead with a retention of 5%. The normal children (Group 1) in our series showed a mean absorption of 50% and a mean retention of 18% (Table I). These results are higher than previous reported figures, all of them for adults, and may suggest that safety recommendations for lead content of foodstuffs for children is too high at the present time.

The children in Group 2 have a significantly lower mean absorption of lead (24% - Table I) and this may be related to a difference in the constitution of the diets between the two groups.

Acknowledgments

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Table I - MEAN DAILY INTAKE AND EXCRETION OF NITROGEN, LEAD, STRONTIUM AND CADMIUM (Units/kg ± Standard Deviation

Element	Subjects & number	Intake total	Excretion			Absorption		Retention	
			Total	Urine	Faeces	Amount	% Intake	Amount	% Intake
Pb (µg)	Normals (11)	10.61 ± 4.03	8.56 ± 3.31	3.43 ± 1.52	5.13 ± 2.70	5.47 ± 1.85	53	2.03 ± 1.40	18
	I.E.M. (6)	14.53 ± 5.91	13.05 ± 5.98	2.50 ± 1.92	10.55 ± 4.30	3.98 ± 3.39	24	1.48 ± 3.92	7
Sr (µg)	Normals (11)	27.43 ± 7.77	23.96 ± 9.74	1.45 ± 3.82	22.51 ± 9.47	4.92 ± 6.10	19	3.45 ± 6.17	14
	I.E.M. (6)	27.40 ± 8.36	30.67 ± 5.87	1.48 ± 1.46	29.20 ± 6.47	-1.78 ± 4.50	-13	-3.28 ± 4.4	-20
Cd (µg)	Normals (11)	1.08 ± 0.41	1.66 ± 1.28	1.16 ± 1.06	0.50 ± 0.30	0.59 ± 0.52	49	-0.57 ± 1.24	-56
	I.E.M. (6)	1.30 ± 0.85	1.33 ± 0.66	0.38 ± 0.39	0.94 ± 0.41	0.36 ± 0.58	19	-0.03 ± 0.3	-10
N (mg)	Normals (10)	351.8 ± 122.7	261.1 ± 66.4	207.6 ± 88.2	26.0 ± 7.1	319 ± 117	90	90.7 ± 109	[illegible]
	I.E.M. (6)	360.7 ± 88.7	221.0 ± 65.6	195.0 ± 63.7	32.8 ± 11.8	335 ± 84	93	139.7 ± 131	34

I.E.M. = Children suffering from Inborn Errors of Metabolism.

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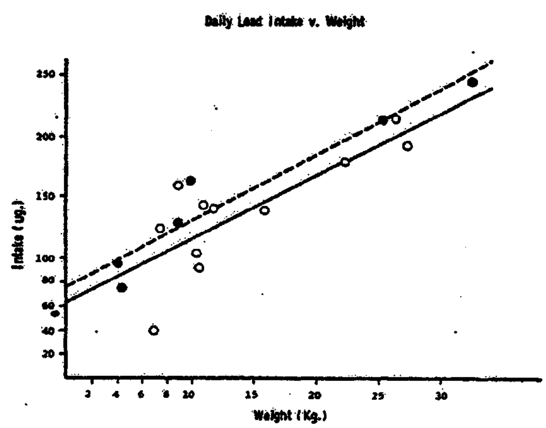
FIG. 1


Daily Lead Intake v. Weight
Intake (ug.)
Weight (Kg.)

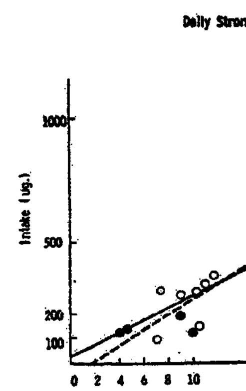
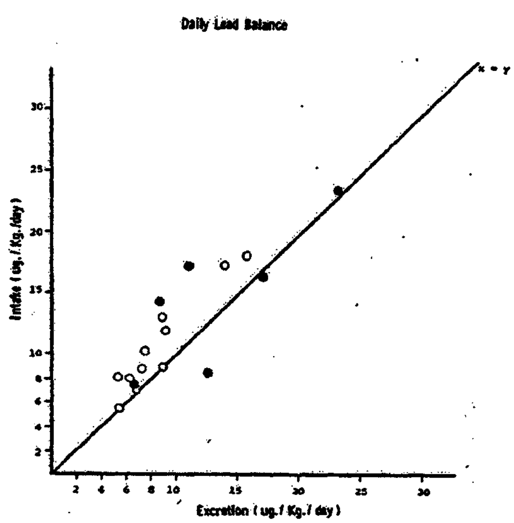

Intake (ug.)

FIG. 2


Daily Lead Balance
x = y
Intake (ug./Kg./day)
Excretion (ug./Kg./day)

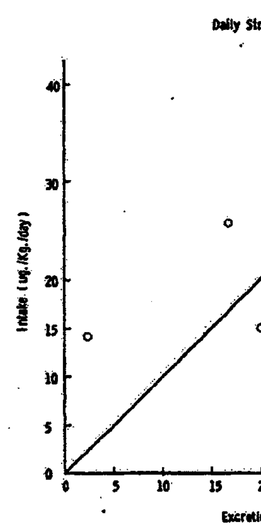

Intake (ug./Kg./day)

FIG. 5

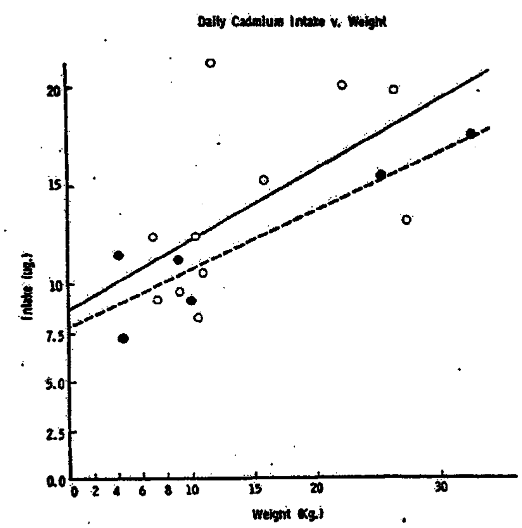
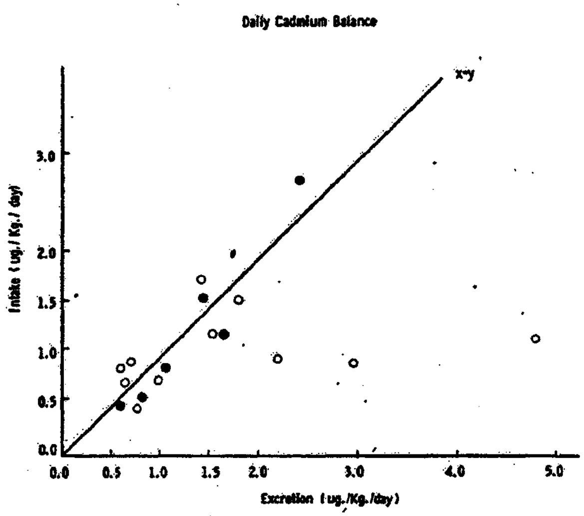


FIG. 6



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