Estimated daily intake of cadmium by children living in the city of Niš, Serbia

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Cadmium is widely abundant in the air, water, soils and foodstuffs. Cadmium exposure and accumulation in the body start at a young age. Accumulation occurs in various tissues and organs, especially in the kidney cortex. This study was initiated to examine the total intake of cadmium among pre-school children. The study group consisted of 275 children aged 1 to 6 years. Estimation of daily intake of cadmium was calculated using the recommended formula, which takes into consideration all the potential means of children's exposure to cadmium. The average daily cadmium intake in children aged 1 to 3 years was 1.06 μg/kg, while for the children aged 4 to 6 years, the average daily cadmium intake was 1.06 μg/kg. Biomonitoring methods were used to assess the effects of a contaminated environment on the children's health. Our research showed that children take in the highest amount of cadmium from food. It is estimated that by the age of 1-3 years, children have accumulated 1.31 mg of cadmium in the body, while those aged 4-6 years have accumulated 8.80 mg. The persistence in the environment of this metal requires a long-term move toward minimizing human exposure through environmental management and preservation of lower cadmium levels wherever possible.

Key words: cadmium, biomonitoring, estimated daily intake, exposure, children.

Cadmium occurs naturally in the environment from the slow process of erosion and abrasion of rocks and soil. As expected, it is abundant in the air, water, soil and foodstuffs. In the environment, cadmium levels reached a peak in the 1960's. Since then, these levels have been continually declining due to improved technology with respect to its production, use and disposal. Nevertheless, environmental cadmium pollution and its effects on human health still represent significant issues[1]. The awareness of the scientific community has been focused on the potential toxicity of cadmium and on the risks presented by its accumulation in the body[2]. Cadmium exposure and accumulation in the body start at a young age. Routes of exposure in children are mostly via food, environmental tobacco smoke and house dust. Accumulation occurs in various tissues and organs, with the most extensive accumulation occurring in the kidney cortex[3]. Renal cadmium concentration is strongly age-related, and usually reaches a plateau at 50 years of age, which correlates with degeneration of the kidney reabsorption function. Cadmium is more powerfully absorbed from the respiratory system than from the gastrointestinal tract. Actual cadmium absorption via inhalation exposure has been estimated to be 30 to 60%. Absorption from the gastrointestinal tract appears to be about 2 to 8%, while dermal absorption is slightly significant. The main route of excretion is via urine. Usual daily cadmium excretion has been reported to be about 0.01%-0.005% of the total body burden[4]. Such extremely slow excretion rate of cadmium is due to a lack of an active biochemical mechanism of elimination and renal reabsorption.

Children's exposure to environmental contaminants is expected to be different and usually higher than that of adults due to differences in physiological function and surface–to–volume ratio. It is very complex to develop and verify exposure factors and transfer rates for children. They are engaged in a wider range of contact activities than adults, and a wider distribution of activities must be considered. Moreover, children have a much bigger surface area relative to body weight than do adults and higher basal metabolic rate and energy requirements. They also have greater oxygen and food requirements per kilogram body weight. The higher breathing rate and food consumption rate in children will result in higher relative exposures to environmental contaminants in air and food[5].

A great number of studies have been conducted in the adult population[1]. However, it is still hard to claim that high concentrations of cadmium, particularly from the air, have an influence on children's health. Studies estimating the percentage of cadmium intake in children have not been performed in Serbia.

The aim of this study was to investigate the total intake of cadmium among pre-school children in Niš, Serbia.

Material and Methods

The study was conducted in the period 2004-2005 in Niš (Serbia), with a population of 300,000. The study included a total of 350 children aged 1 to 6 years at the beginning, but we collected complete documentation for only 275 children (138 boys, 137 girls). The participants were chosen from an urban area, which is characterized by heavy traffic and relatively high air pollution.

A personal meeting with parents was conducted in the homes and kindergartens of the participants, during which information about the aims, the performance and the expected results of the study were shared. The parents gave permission for their children to be included in the study. A short medical check-up revealed no acute or chronic illnesses. All children consumed a mixed diet and none was on a special diet.

Dietary data for this analysis were obtained from food diaries in which the kind and amount of the food ingested were entered. Parents recorded the details about the quantity and type of food consumed by their children during the period of one year in different seasons (spring, summer, autumn, winter) for 5 days, and we analyzed dietary data from four weeks (20 days). Parents were instructed to include all foods consumed at home and outside the home. The checklist contained 40 food items classified into eight categories: cereals and cereal products (N=5), vegetables (N=7), fruits (N=5), meat (N=7), fats (N=3), milk and milk products (N=5), sweets (N=5), and juices (N=3). The list of food items represent a list of food items that are either consumed in great quantities or contain high chemical residue levels according to monitoring data, or a combination of the two. Participants recorded the food item and its quantity consumed on each day by checking the corresponding number and quantity on the checklist.

Children's body weight was measured to the nearest 0.1 kg by portable scale.

The accredited laboratory in the Institute for Public Health, Niš participated in order to determine the concentration of cadmium in the collected samples by standard methods. Reading of the results was done by the method of graphite cuvette on atomic absorption spectrometry (AAS).

The air samples were collected in the tested territory during the regular monitoring system, which was from the birth of the children (1999-2005) continuing once a week at five sampling sites. During the research, care was taken that all days of the week were equally processed.

Soil samples were tested only once (in September 2004) in a layer 20 cm in depth in the children's playgrounds, parks, backyards of the buildings were they lived and the yards of the nursery schools they attended. A total of 50 samples were tested.

During the investigation period, food samples were collected from the market as a part of the regular monitoring system. Individual food items were at first homogenized and then dry ashed at 450°C and dissolved in a concentrated HNO_3 and adjusted to a certain volume with deionized water.

Estimation of daily intake (EDI) of cadmium was calculated using the recommended formula[6], taking into consideration all the potential routes of cadmium exposure in children.

EDI = EDa + EDw + EDs + EDt + EDws + EDss

EDa - the amount of cadmium inhaled through the air,

EDw - cadmium intake by drinking water,

EDs - cadmium intake by eating soil,

EDt - cadmium food intake,

EDws - cadmium amount absorbed through skin contact with water,

EDss - cadmium amount absorbed through skin contact with the soil.

The numerous exposure pathways and routes require a different equation for each combination. However, all equations are to some extent similar. The general equation is:

$$ED = \frac{C \times CR \times EF}{BW}$$

Where,

ED = Estimated dose (generally the number of milligrams of the contaminant that enter the body for each kilogram of body weight (mg/kg/day).

C = Concentration of the contaminant in the exposure pathway being considered.

CR = The amount of water, food, air, soil, etc., which is swallowed, inhaled or comes into contact with the skin in one day (g/day).

EF = Exposure factor. This indicates how often the children are exposed during the year and the number of years that this pattern has been repeating itself.

BW = Body weight - the average children's body weight (kg).

Biomonitoring methods were used to assess effects of the contaminated environment on the health of the children[7,8]. Morning urine samples were collected in acid-washed polyethylene containers and were stored frozen (-20°C) until transfer to the analytical laboratory in the Institute for Public Health, Niš. A 2% random sample of specimen-collection containers was tested and certified "cadmium free". Investigators determined cadmium concentrations of urine by graphite-furnace AAS (Perkin-Elmer A Analysis T 600), after acidification of urine[9]. The minimum detection limit (MDL) for cadmium was 0.05 μg/L in urine. Whenever the assays yielded a negative finding for cadmium, the authors assumed the true value to be half the MDL. Assay results below the MDL were found in 2% of the children in the urine analyses. According to the World Health Organization (WHO)[4], the amount of cadmium excreted daily in urine represents only about 0.005-0.01% of the total body burden. For the calculation of cadmium body burden, we used 0.01% and children's daily excretion of 900 ml of urine.

Results of the examinations were processed by mathematical and statistical methods. Arithmetic mean values (Aver), standard deviation (±SD), geometric mean (Geomean), medians (Me), min, max and 10^{th}, 70^{th} and 98^{th} percentiles (C_{10}, C_{70}, C_{98}) were calculated. The analysis was performed using statistical software SPSS® for Windows ™, release 8.0 (SPSS Inc, Chicago, IL, USA).

Results

The characteristics of the examined children are shown in Table I. The average body weight of children aged 1 to 3 years was 13 kg, while for the children aged 4 to 6 years, the average body weight was 15 kg. Information about air inhalation (m^3), total soil adhered (mg/day) and total body surface area (cm^2) in children of this age were taken from the literature.

Table II shows the concentrations of cadmium in different mediums of the environment. The results support our expectations that cadmium levels in the air are very high (up to

Table I. Characteristics of the Examined Children

Age	Gender M	Gender F	Gender Total	Aver±SD BW (kg)	Air inhalation (m^3)*	Soil ingestion (mg/day)*	Total soil adhered (mg/day)*	Total body surface area (cm^2)*
1-3	73	54	127	13.38±2.61	5	50	3500	5780
4-6	65	83	148	15.32±3.84	12	35	5800	9660

*literature data[6].

Aver: Arithmetic mean. SD: Standard deviation. BW: Body weight.

Table II. Cadmium Concentration in the Environment (1999-2005)

Samples	No. of samples	C_{10}	C_{50}	Aver ±SD	C_{70}	C_{98}	Max
Air (μg/m³)	1820	5.0	14.5	16.2±8.3	41.2	98.5	102.5
Soil (mg/kg)	50	76.5	100.0	96.2±41.8	108.5	120.0	150.0
Drinking water (mg/L)	250	0.0	0.0	0.0±0.0	0.0	0.0	0.0
Food (μg/kg)	2215	1.2	15.0	20.3±2.6	31.5	330.0	500.0
Cereals and products	511	0.5	14.5	13.9±3.2	15.7	30.2	330.0
Vegetables	176	0.2	8.2	21.2±3.1	17.0	89.5	150.5
Fruits	203	5.0	20.5	26.7±2.3	48.5	50.0	50.0
Meat	194	4.2	8.2	14.0±1.5	17.2	59.2	150.0
Fats	79	0.2	7.2	15.0±2.5	22.0	42.2	42.5
Dairy products	511	1.2	3.7	9.4±1.6	8.2	20.7	95.5
Sweets	189	0.5	5.7	16.1±3.0	17.5	69.5	73.0
Juices	352	1.5	4.7	10.3±1.9	11.5	40.5	500.0

Aver: Arithmetic mean. SD: Standard deviation.

102 μg/m³). The concentrations of cadmium in the ground were lower (to 96 mg/kg). In the examined samples of drinking water from the city plumbing, even after concentration of the samples 10 times, no measurable concentrations of cadmium were detected.

Concentrations of cadmium in the groceries accessible on the market in the examined territory varied according to grocery type. The highest average value was in fruit (26.69 μg/kg) while the maximum measured value was determined in juices (500 μg/kg).

The recorded data about the quantity and types of food consumed by the children is shown in Table III. children in both age groups consumed mostly cereals and cereal products in their diet. A very frequent intake of sweets was determined (121-128 g daily), as well as inadequate intake of dairy products (183-210 g daily).

According to dietary data using formula[6], the daily intake of cadmium in the examined children was calculated. In the existing formula, the values of Edw (cadmium intake by drinking water) were not taken into consideration because there were no measurable concentrations of cadmium in the examined samples of water. The results are shown in Table IV.

Among examined food, cereals and their products had the highest concentration of cadmium (41 to 45%), while fat and sweets showed the smallest concentration of cadmium. Daily cadmium intake in children aged 1-3 years was 0.98 μg per kg body weight, and in children aged 4-6 years was 1.06 μg per kg body weight.

The concentration of cadmium in children's 24-hour urine samples was determined. The average concentration of cadmium in urine was 0.16 μg/g creatinine in children aged

Table III. Average Daily Amounts of Various Food Groups Consumed by the Examined Children (g)

	Age			
	1-3		4-6	
Food group	Amounts	%	Amounts	%
Cereals and products	249	25	346	29
Vegetables	143	15	162	13
Fruits	120	8	160	13
Meat	62	6	85	7
Fats	30	3	35	3
Dairy products	183	19	210	17
Sweets	121	12	128	10
Juices	75	8	100	8
Total	983	100	1226	100

Table IV. Estimated Daily Cadmium Intake (EDI) in Children

Pathway of exposure (µg/kg/day)	Age 1-3	Cd intake (%)	Age 4-6	Cd intake (%)
Air inhalation	0.268±0.135	27	0.491±0.247	46
Soil ingestion	0.0001	1	0.0001	1
Skin through contaminated soil	0.009±0.001	0.02	0.008±0.001	0,01
Food ingestion	0.703±0.090	72	0.567±0.073	53
Cereals and products	0.288±0.066	41	0.266±0.061	45
Vegetables	0.076±0.011	11	0.071±0.010	12
Fruits	0.096±0.008	14	0.063±0.005	11
Meat	0.073±0.008	10	0.027±0.003	4
Fats	0.038±0.006	5	0.007±0.001	1
Dairy products	0.041±0.007	6	0.125±0.021	21
Sweets	0.028±0.005	4	0.011±0.002	2
Juices	0.064±0.012	9	0.024±0.005	4
Total (µg/kg/day)	0.981±0.226		1.066±0.321	
Total (µg/day)	12.743±2.936		15.984±4.813	

1-3 years and 0.23 µg/g creatinine in those aged 4-6 years. Total cadmium body burden was calculated considering the fact that the concentration of secreted cadmium during the day is about 0.01% of total body saturation. It is estimated that the children aged 1-3 years had accumulated 1.31 mg of cadmium in the body while those aged 4-6 years had accumulated 8.80 mg (Table V).

Discussion

Assessment of environmental pollution exposure in children remains difficult. For several reasons, children's exposure to cadmium is likely to be much greater than that of adults. All these factors make a great difference in the way an organism reacts in the presence of pollutants given the extent of exposure. It should be emphasized that children's bodies, in the period of rapid growth and development, have significantly increased sensitivity to the harmful substances to which they are exposed[10,11].

Recent studies have investigated exposure to cadmium in relation to its potential influence on the health of adults[12-15]. Only a few studies, however, have investigated its potential influence on children's health[16-19].

The city of Niš has dealt with the problem of cadmium air pollution for a long time because of the tobacco factory present in the city for more than 50 years. According to the WHO data[4], cadmium mean annual levels in industrial areas of Europe are 1-20 µg/m^3. In Niš, the mean value in the investigation period was 16 µg/m^3. It is of interest to note that these cadmium concentrations could have a significant influence on cadmium intake by inhalation, the values of which were 0.2680 and 0.4910 µg/kg/day or 3.48 and 7.36 µg/day in the 1-3 and 4-6 age groups, respectively. This is 10 times more than the estimate of the WHO, which states that the average amount of cadmium inhaled daily by humans in industrialized areas should not exceeded 0.4 µg for adults; in this study, children aged 1-6 years were tested.

Cadmium in food comes to a great degree from atmospheric cadmium, as a consequence of foliar absorption or root uptake of cadmium deposited in the soil. According to these results, the soil in our region does not show significant pollution, but the pollution in some grocery groups (for example, meat) is higher in comparison with the literature data.

Table V. Cadmium Concentration in Urine (µg/g creatinine) in Children and Body Burden

Age	Min	C50	Aver.±SD	Geomean	Max	Body burden (mg)
1-3	0.005	0.08	0.16±1.23	0.13	0.27	1.31
4-6	0.005	0.11	0.23±1.55	0.18	0.42	8.80

Aver: Arithmetic mean. SD: Standard deviation. Geomean: Geometric mean.

Cadmium intake by food depends on nutritional habits, frequency of foodstuff intake and cadmium levels in the foodstuff. Our research shows that the highest concentration of cadmium consumed by children comes from the group of cereals and cereal products (41-45%), vegetables (11-12%) and dairy products (6-21%).

Similar studies have shown the great variations in daily intake of cadmium in children. Researchers from Korea[19] found that the average daily intake of cadmium via food was 0.457 μg/kg body weight. In another study performed in Dutch children aged 1-6 years[20], the average daily intake of cadmium via food was 0.32 μg/kg body weight. Both of the studies showed that children from European countries take in much less cadmium via food in comparison to our country.

With respect to the total amount of intake of cadmium according to food groups, a comparison of our results with those of the Netherland group show that intake of cadmium depends on nutritional habits. The total diet study of Dutch children aged 1-7 years showed that contribution of product groups to cadmium dietary intake was 38% for cereals and cereal products, 25% for vegetables and 11% for juices[21].

According to the Council of Europe[22], daily intake of cadmium via food in adults in Europe is from 9 μg (Netherlands) to 64 μg (Italy) daily. In most other countries, it is about 12 to 30 μg/day. The data that we are evaluating[23-27] are not completely adequate for comparison, first because the data relate to adults and second because different means were used to measure the cadmium concentrations in food (analysis of food inventory, total diet, analysis of canteen meals and duplicate meals).

The WHO[3,4] has established a provisional tolerable weekly cadmium intake (PTWI) of 7 μg/kg body weight. This PTWI value corresponds to a daily tolerable intake level of 70 μg of cadmium for the average 70 kg man. There are no recommendations for children and it cannot be determined according to body weight, because it is considered that even very low concentrations of cadmium can damage a child's health.

Using the formula recommended by Health Canada[6] in children, total daily intake of cadmium is calculated by all means of its intake. Intake by inhalation is from 0.2680 to 0.4910 μg/kg/day; soil ingestion and skin exposure through polluted soil is almost negligible; while the intake via food is from 0.5667 to 0.7035 μg/kg/day. According to our calculations, the total intake of cadmium in children aged 1-3 years is 0.98 and in children aged 4-6 years is 1.06 μg/kg/day. These data are considerably higher than the results reported worldwide[20,21].

Since the greatest concentration of cadmium is taken in via air and food, biomonitoring was done to determine the concentration of cadmium in urine in the tested children, in order to estimate if there is some accumulation of cadmium in the body and to determine if there will be any consequences on the children's health. Some researches point out the high correlations that exist between cadmium in urine (CdU) and kidney cortex cadmium, which gives a basis for the use of urinary cadmium determinations as an index of cumulative exposure to cadmium in the general population[28-32].

In our study, geometric means of CdU were 0.13 and 0.18 μg/g creatinine in the two age groups, respectively. In a recent cross-sectional study (18) performed on 800 children living around historical nonferrous smelters in France, the Czech Republic and Poland, it was found that geometric means of CdU ranged between 0.22 μg/g creatinine (Czech Republic) and 1.22 μg/g creatinine (France).

Over the past decade, various studies of both occupationally and environmentally exposed populations have shown that tubular proteinuria occurs at doses of CdU of 2-4 μg/g creatinine. The result points out (28,29) that early renal effects in the general population may occur with CdU concentration above 2.0 μg/g creatinine.

Additionally, cadmium exposure in childhood may have a strong impact on renal function, particularly tubular reabsorption. Literature information makes evident that cadmium exposure is associated with subtle tubular effects. At recent high environmental exposure levels, cadmium remains an environmental pollutant of continuing concern. Cadmium exposure at an early age should be limited as much as possible to prevent direct effects on children and to prevent its accumulation, which may have serious health effects that manifest only at older ages. The persistence in the environment of this metal requires a long-term approach to minimizing human exposure through environmental management and maintenance of lower cadmium levels wherever possible.

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