Review

A Review on the Cadmium Content of Rice, Daily Cadmium Intake, and Accumulation in the Kidneys

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Abstract: A Review on the Cadmium Content of Rice, Daily Cadmium Intake, and Accumulation in the Kidneys: Tomoyuki KAWADA, *et al.* Department of Public Health, Gunma University School of Medicine—The body burden of cadmium primarily depends on the daily intake of the element in food, and thus the geographical differences in cadmium content in foods and the daily intake of cadmium should be studied. There is a food chain from soil through plant and animal foods to man. Estimation of daily cadmium intake according to the geographical region is important for monitoring environmental cadmium pollution and health effects. In the 1990s, the daily intake of cadmium and accumulation in the kidney were reported. Japanese have a relatively high daily intake of cadmium, although the percentage daily cadmium intake obtained from rice decreased from 50% in 1970 to 34% in 1994. This change is proportional to the change in average rice consumption from 261 g/day in 1970 to 182 g/day in 1994. These changes also indicate a reduced cadmium burden in the past twenty years, from 35–50 $\mu\text{g/day}$ to 30 $\mu\text{g/day}$. The cadmium level in the renal cortex of Japanese is the highest in the world, but the cadmium in the kidney has been decreasing in most Japanese.
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Key words: Cadmium in rice, Daily intake of cadmium, Cadmium accumulation in the kidneys, General inhabitants

In mammals cadmium is known to accumulate exclusively in the kidneys, and it has a long biological half-life in the human body, ranging from 10 to 33 years^{1,2)}. The amount of cadmium that has accumulated in the kidneys is a function of age and/or daily cadmium intake, and the latter is mainly from food, beverages and smoking²⁻⁵⁾. Cadmium in drinking water and in the atmosphere contributes little

to the daily intake of cadmium⁶⁾.

Man is an element in an ecosystem. The cadmium pathways to man are soil-plant-animal-man and soil-plant-man. Cadmium-rich soil generally results in cadmium-rich food, and geographical differences have been reported in daily cadmium intake and cadmium accumulation in the kidneys^{2,4,7,8)}.

Earlier investigators reported finding that Japanese have the highest renal cadmium levels in the world, followed by rice-eating ethnic groups such as the people of Thailand, Hong Kong and Taiwan, with the lowest levels in people in the United States, Switzerland, India, Nigeria, and Rwanda-Burundi^{2,9)}. Data for cadmium concentrations in the human renal cortex range from an average of 10 to 30 $\mu\text{g/g}$ wet weight for Europeans, Americans and Africans, but from 65 to 115 $\mu\text{g/g}$ wet weight for Japanese (Table 1)¹⁰⁻¹⁶⁾. Renal cadmium content is governed by cadmium absorbed from the digestive tract and respiratory organs that comes from food, beverages and cigarettes, which originate in the soil. The cadmium content of plants varies from place to place on the earth. Baseline studies on environmental monitoring of cadmium is needed, but the data are very limited^{2,3)}.

Suzuki and Lu previously estimated the daily cadmium intake in Japan, the United States and Indonesia by food and feces analysis. The daily cadmium intake of two men in Tokyo averaged 48.2 and 46.9 $\mu\text{g/day/person}$ based on a 30-day another meal method, versus 35.9 and 36.0 based on a 30-day feces analysis¹⁷⁾. The daily cadmium intake in Houston, Texas, ranged from 11.9 to 18.2 based on food analysis and a market-basket survey¹⁸⁾. The daily cadmium intake on Java Island, Indonesia, was estimated to be 17.2 based on food analysis of a 5-day menu¹⁹⁾.

The authors have reviewed recent data on cadmium accumulation and daily intake to assess geographical differences, in addition the data obtained in our own surveys in Japan, the United States and Indonesia from 1972 to 1985. The samples were mainly measured by atomic absorption spectrophotometry (flame or flameless). The target subjects were male and female

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Table 1. Geographical difference in cadmium concentration in the kidney cortex in several countries in the 1960s, 1970s and 1980s

Country	Ref.	Age	sex	Mean (SD)	Analytical method
USA	9			29.1	Freeze-dry, emission S
Switzerland	10			31.1	Dry, emission S
Rwanda-Burundi	10			9.8	Dry ash, emission S
Nigeria	10			23.3	Dry ash, emission S
Indonesia	—	46–59	M & F	19.5 (0.33) ^G	Wet ash, Flameless AAS
Sweden	15	40–49	Male	19.3 (1.80) ^G	Dry ash, Flame AAS
Sweden	15	40–49	Female	25.8 (1.65) ^G	Dry ash, Flame AAS
Sweden	15	50–59	Male	15.6 (2.48) ^G	Dry ash, Flame AAS
Sweden	15	50–59	Female	21.2 (2.05) ^G	Dry ash, Flame AAS
West Germany	11	41–50	Male	23.2 ^G	Wet ash, Flameless AAS
West Germany	11	51–60	Male	17.5 (1.3) ^G	Wet ash, Flameless AAS
West Germany	11	41–50	Female	16.8 (1.3) ^G	Wet ash, Flameless AAS
West Germany	11	51–60	Female	12.7 (2.1) ^G	Wet ash, Flameless AAS
Japan	12	40–59	Male	87 (37)	Flame AAS
Japan	12	40–59	Female	99 (20)	Flame AAS
Japan	13	39 (Mean)		58.8	Wet ash, Flame AAS
Japan	14	40–49		85.1 (47.49)	Wet ash, Flame AAS
Japan	14	50–59		125.3 (56.74)	Wet ash, Flame AAS
Japan	15	40–49	Male	43.2 (1.65) ^G	Wet ash, Flame AAS
Japan	15	40–49	Female	82.7 (1.51) ^G	Wet ash, Flame AAS
Japan	15	50–59	Male	65.0 (2.17) ^G	Wet ash, Flame AAS
Japan	15	50–59	Female	63.2 (1.42) ^G	Wet ash, Flame AAS
Japan	16	40–49	Male	114.1 (37.2)	Wet ash, Flame AAS

G; Geometric mean and/or geometric standard deviation, S; spectrophotometer

AAS; atomic absorption spectrophotometer

inhabitants in non-cadmium-polluted areas and their average age was 50 years.

The purpose of this review was to identify trends in cadmium exposure in ordinarily inhabitants, especially net cadmium intake by ingestion. This will be useful as baseline data for cadmium intake except via smoking or occupational exposure.

Geographical differences in the cadmium content in rice

Many surveys have reported finding showing that rice produced in Japan contained the highest cadmium levels among samples collected from several different areas in the world^{20, 21)}. A survey on the cadmium content of rice in samples from 22 countries by Masironi *et al.*²¹⁾ revealed the lowest level, 2 ng/g, in rice from Brazil and the highest level, 65 ng/g, in rice from Japan. The Japanese Government's program to replace polluted rice field soil is being carried out. Suzuki *et al.* reported an arithmetic mean and SD in Indonesian rice of 40 ± 42 ng/g and a geometric mean of 31 ng/g²²⁾. The mean and SD for cadmium in rice from Spain was 32.2 ± 25.94 ng/g²³⁾. In

China, the average value for cadmium in polished rice from a non-polluted area was 60 ng/g²⁴⁾. These results show that considerable geographical differences exist in the cadmium content of rice.

The rice of West Java has been found to have double the cadmium content of rice from Central and East Java²²⁾. The soil type in West Java is *Ultisol*, as opposed to *Vertisol* in East Java. The soil type in Western Japan is also *Ultisol*, and this may explain the higher cadmium levels²⁵⁾.

The cadmium content of soil also differs very much from place to place, and this may be responsible for the difference in the amount of rice in plant foods produced in soil. The correlation between cadmium content in soil and rice is low within the same area but high between different areas²⁶⁾.

Daily cadmium intake

There are four ways of estimating of daily cadmium intake. The first is another meal method or duplicate portions method. The total diet is usually mixed or homogenized, and part of it is taken for analysis. The second method is the market-basket method for

Table 2. Geographical difference in daily intake of cadmium by duplicate meal method published in the 1990s

Country	Ref.	Mean (SD)	Analytical method
Spain	23	18.18	Wet ash, Flameless AAS
Germany	29	9.7 (8.1)	Dry ash, Flame AAS
Sweden	30	11.1 (4.2)	Dry ash, Flame AAS
Sweden	31	12	Flameless AAS
China	32	9.9 (2.33) ^G	Wet ash, Flameless AAS
Taiwan	33	10.1 (1.70) ^G	Wet ash, Flameless AAS
Croatia	34	17.34	Dry ash, Flame AAS
Finland	35	14.5 (3.1)	Flameless AAS
Korea	36	21.2 ^G	Wet ash, Flameless AAS
Japan	32	32.1 (1.93) ^G	Wet ash, Flameless AAS
Japan	37	30.0 (2.09) ^G	Wet ash, Flameless AAS

G; Geometric mean and/or geometric standard deviation

AAS; atomic absorption spectrophotometer

Table 3. Geographical difference in cadmium concentration in the kidney cortex published in the 1990s

Country	Ref.	Smoke	Mean (SD)	Analytical method
Poland	4	–	28.5 (1.9) ^G	Wet ash, Flame AAS
Spain	39	+ & –	14.6 (5.9)	Wet ash, Flameless AAS
Poland	40	–	16.5 (1.8) ^G	Wet ash, Flame AAS
Poland	41	–	26.3 (23.5)	Wet ash, Flame AAS
Germany	42	+ & –	55.2 (50)	ICP
Sweden	43	–	62.8	Wet ash, Flameless AAS
Japan	44	+ & –	52.2 ^G	Wet ash, AAS*

G; Geometric mean and/or geometric standard deviation

*; Flame or flameless atomic absorption spectrophotometer

Some dissociation existed in daily intake of cadmium and its accumulation in the kidneys for example in Germany and Sweden.

individuals and total diet method for populations. Foods and beverages are sampled and bought in representative retail shops in the area and analyzed for the element. The cadmium content of the same food item is averaged and multiplied by individual food consumption data or by the national food balance sheet data. The third method is estimation of daily cadmium intake from daily cadmium excretion in feces. Daily cadmium in feces equals about 95% of the daily oral cadmium intake²⁷⁾. Approximate daily cadmium intake is roughly calculated from the feces data multiplied by a factor of 100/95²⁸⁾. The last method is estimation by using a nomogram indicating the relation between the average concentration of cadmium in the kidneys at age 50 and the average daily cadmium intake in an area or a country.

Daily cadmium intake is reported to be low in Germany²⁹⁾, Sweden^{30, 31)}, China³²⁾ and Taiwan³³⁾. The

intake values in Croatia³⁴⁾, Finland³⁵⁾ and Spain²³⁾ are moderate. Most mean values range from 10 to 20 $\mu\text{g}/\text{day}$. Data reported from Korea³⁶⁾ and Japan^{32, 37)} are high, ranging from 20 to 30 $\mu\text{g}/\text{day}/\text{person}$ (Table 2). This is consistent with the moderate accumulation of the element in the renal cortex of Japanese^{2, 38)}.

Cadmium in the renal cortex

The renal cortex is a critical organ in terms of long-term exposure to cadmium. Cadmium content data for the renal cortex reported recently have shown the lowest values in Spain³⁹⁾ and Poland^{4, 40, 41)} and relatively high values, exceeding 50 $\mu\text{g}/\text{g}$, in Germany⁴²⁾ and Sweden⁴³⁾. In Japan, Koizumi *et al.* reported 130 and 21 $\mu\text{g}/\text{g}$ as GM $\times \div$ GSD, respectively, from which a geometric mean of 52.2 $\mu\text{g}/\text{g}$ was calculated⁴⁴⁾ (Table 3). The WHO recommendation⁴⁵⁾ states that the critical concentration

of cadmium in the renal cortex is about $200 \mu\text{g/g}$. The standard deviation of the data for Germany is 50, so that the values in under 1% of the target population exceed $200 \mu\text{g/g}$.

Comments

The daily cadmium intake and renal cortex cadmium concentration data over the past quarter of a century are

plotted in Fig. 1. Rice eaters have been said to ingest about a half or more of their daily cadmium intake from rice⁴⁶⁾. The latest data in Japan show that one third of the daily cadmium intake comes from rice. Compared with the data for Japan in the 1970s^{17, 38, 46)}, which ranged from 35 to $50 \mu\text{g/day}$, the daily intake of cadmium has decreased recently. This may be partly attributable to decreased rice consumption, which averaged 261 g/day

Fig. 1. Daily intake of cadmium and its concentration in the renal cortex. Over $100 \mu\text{g/g}$ of cadmium in the renal cortex was also reported in the 1970s and 1980s in Japan.

in 1970 and 182 g/day in 1994⁴⁷⁾, in addition to the elimination of polluted rice from the market and increased consumption of imported foods.

The criteria for food being a good indicator of cadmium intake are: large and widespread consumption, ubiquitous cultivation throughout the world, and easy sampling, transportation, and conservation²⁾. Rice, wheat, and a few vegetables, such as carrots, are therefore the best indicator foods for cadmium. Although the consumption of rice has been decreasing, e.g., in Japan, daily cadmium intake can be roughly estimated by analysis of the cadmium content in the rice people eat. Rice is the best indicator food for cadmium monitoring in rice-eating ethnic groups. Sources of daily cadmium intake in non-rice-eaters are cereals, vegetables and potatoes, although non-rice-eaters are usually not in the high-risk group for cadmium intake.

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