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Cadmium in foods and the diet

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Summary. Information on the sources of cadmium in food are presented and the effects of raised environmental levels of cadmium on the concentration of cadmium in plant based foods, fish and shellfish, meat and offals, and dairy produce are discussed. Information is also presented on normal dietary intakes of cadmium and how these intakes may be elevated by environmental pollution or atypical dietary habits. The estimation of dietary intakes of cadmium using data about extreme intakes of specific foods is described.

Introduction

Cadmium is naturally present in all parts of the environment; it is present in all soils and sediments at concentrations which are generally < 1 mg/kg[31] and its total concentration in unpolluted seawater, where it exists mainly as chlorocomplexes, is generally < 1 µg/kg[27]. The concentration of cadmium in air in non-industrialized areas rarely exceeds 2.5 ng/m^3 which is equivalent to 3 ng/kg[5]. Consequently, all food, whether it be of plant or animal origin, is exposed to and contains cadmium. Unlike many other metals, cadmium has come to be used by man only relatively recently. It was identified as an element in 1817; its large scale use dates from the 1940s; and it is only in the last 3 decades that serious consideration has been given to cadmium as a food contaminant.

The use of cadmium may increase, in several ways, the extent to which it is found in foods: 1. deposition from the atmosphere onto crops growing near sources of cadmium emissions, for example smelters[2]; 2. discharge and deposition of cadmium in water and subsequent uptake by animals and other food grown in water[37]; 3. the use on land of phosphatic fertilizers which contain high concentrations of cadmium[22]; 4. the disposal to land or to sea of cadmium contaminated sewage sludge[17]; 5. the use of cadmium containing food contact materials, such as decorated glazed ceramic ware[14,16]; 6. the dispersion through mining activities of material richer in cadmium than the surrounding environment[4].

This paper discusses the concentrations of cadmium normally present in food and presents information showing how these concentrations are elevated by environmental cadmium pollution. Finally, information is presented about the dietary intake of cadmium with particular emphasis on the estimation of extreme intakes.

Cadmium in food and the impact of environmental pollution

For the purposes of simplicity, consideration of normal concentrations of cadmium in food and the impact that environmental pollution has on them has been divided into 4 sections. Each section deals with a specific class of food.

Plant based foods. Individual samples of plant-based foods grown in uncontaminated environments rarely contain more than 0.2 mg/kg on a fresh weight basis[26] (unless otherwise stated all cadmium concentrations in food are reported on a fresh weight basis) and average values for cadmium in specific foods are unlikely to exceed 0.1 mg/kg. Some root crops, such as carrot and parsnip, and some leafy crops, such as lettuce and spinach, tend to contain more cadmium than do other plant foods. The same is true of cereals, perhaps by virtue of their relatively high dry matter content. In contrast, fruits and fruit juices contain uniformly low concentrations of cadmium. Evidence in support of this is presented in table 1 which compares normal concentrations of cadmium in plant-based foods with those found in foods grown in soils containing more than 1 mg/kg of cadmium. It has been assumed that the concentration of cadmium in the soils in which the normal crops were grown was < 1 mg/kg. The data demonstrate that, unlike the case with lead[6], plants tend to take up and translocate cadmium from soil. The process by which this happens is not well understood and much effort is currently being expended on research into this problem.

Cadmium pollution of the soil often arises because of excessive applications of sewage sludge or because of the dispersion of mine spoil to the environment. There is also some evidence[22] to show that the use of phosphatic fertilizers, all of which contain some cadmium, has caused an increase in the cadmium content of cereal crops. Analysis of aged samples of cereals did not indicate that there had been a marked change in the cadmium content of cereals grown in the United Kingdom (UK) over the last century[18]. The current awareness about the risks to health from cadmium has done much to reduce emissions to the air and to reduce the dispersal of cadmium-contaminated industrial waste to the environment. However, cadmium-containing effluents can still be discharged into the sewers and the consequent treatment of sewage results in the concentration of cadmium in sewage sludge. Much of the sewage sludge produced in the UK is desposed of on land where it provides a source of organic matter and plant nutrients. Many countries have recommended maximum limits to regulate the addition of cadmium in sewage sludge to agricultural land, and in the UK the level is not to exceed more than 5 kg/ha over 30 years[10]. It is only by controlling the discharge of cadmium into the sewers that limitation of future increases in the cadmium content in the soil and, therefore, in food, can be achieved.

Fish and shellfish. One of the problems encountered in monitoring fish for cadmium is that most species contain so little cadmium that it is difficult to determine accurately the concentration of cadmium without resorting to sophisticated and time-consuming analytical techniques and without taking great care to avoid adventitious contamination. Table 2 presents information gathered as part of a routine monitoring exercise carried out in the UK. The samples of fish were taken from both distant water and

Table 1. Cadmium in crops grown on land containing elevated concentrations of cadmium compared with cadmium in normal crops

Crop	Mean concentration of cadmium in crop (mg/kg, fresh weight basis)	
	Crops grown on land with elevated cadmium concentration[a]	Normal crops
Lettuce	0.18 (50)[b]	0.06 (17)
Cabbage	0.04 (45)	0.01 (22)
Spinach	0.63 (11)	0.08 (4)
Carrot	0.15 (2)	0.05 (13)
Potato	0.14 (7)	0.03 (20)
Plums	0.01 (7)	< 0.02 (5)
Corn grain	0.06	0.03

[a] Soils containing greater than 1 mg/kg of cadmium.
[b] Number of samples in parenthesis.

Table 2. Cadmium in fish and shellfish

Fish	Mean cadmium concentration (mg/kg)
Bass	0.2 (14)[a]
Cod	0.16 (343)
Herring	0.18 (171)
Monkfish	0.02 (10)
Whiting	0.17 (360)
Sea trout	0.03 (68)
Salmon	0.03 (17)
Pink shrimps	0.2 (7)
Winkles	0.2 (1)[b]
Whelks	1.8 (4)
Crabs (brown meat)	4.3 (43)
Crabs (white meat)	0.2 (44)

[a] Number of samples in parenthesis.
[b] Analysis made on 250 samples bulked together.

coastal water about the UK. The limits of detection varied according to the analytical techniques employed, but it is clear that the average concentration of cadmium is certainly less than 0.2 mg/kg and there is evidence[19] to indicate that the cadmium concentrations in fish are often < 0.005 mg/kg. Shellfish contain higher concentrations of cadmium than do most other foods. With exceptions of lobster, whelks and crabs, shellfish taken from unpolluted waters rarely contain an average cadmium concentration in excess of 1 mg/kg, although individual samples sometimes contain more than this. In contrast, whelks, the body meat of lobsters and, especially, brown body meat of crabs often contain an average cadmium concentration of more than 1 mg/kg. Pollution of the marine environment, for example by discharge of cadmium-containing effluents to rivers and estuaries, appears to have resulted in increased concentrations of cadmium in shellfish[36,37] but not fish.

Meat and offal. The concentration of cadmium in meat, other than offal, is uniformly low, average concentrations being < 0.05 mg/kg. Animal offal, especially liver and kidney, generally contains an average cadmium concentration in excess of 0.05 mg/kg; individual samples of kidney often contain more than 0.5 mg/kg of cadmium. This is not surprising since the kidneys and, to a lesser extent, the liver of animals, including man, accumulate about 65% of the cadmium absorbed by the body and the major area of concern about the effects of cadmium on man is because of its nephrotoxicity[32].

Animals grazing on land contaminated by cadmium, or consuming fodder grown on contaminated land yield meat which contains normal or slightly elevated concentrations of cadmium[17,33]. However, the liver and kidneys from animals consuming elevated amounts of cadmium contain significantly more cadmium than is usual and it is prudent that this offal should not be consumed.

Dairy produce and other foods. Milk, cheese, butter, oils and fats, and eggs contain uniformly low concentrations of cadmium. Average concentrations of cadmium in butter, cheese, lard and margarine do not exceed 0.05 mg/kg and individual samples rarely contain more than 0.1 mg/kg[26]. Normal average concentrations of cadmium in cow milk are generally less than 0.005 mg/l[12] and in eggs the average concentration is 0.01 mg/kg[21]. Milk from cows whose intake of cadmium is high does not appear to contain elevated levels of cadmium[33]. It has been reported that eggs are unlikely to contain more than 0.05 mg/kg of cadmium unless the feed contains more than 13 mg/kg[9]. Supporting evidence for this was found at the English village of Shipham, where previous mining activity has caused localized elevated cadmium levels in soil. Eggs from chickens and ducks at Shipham contained < 0.01 mg/kg of cadmium[34].

Dietary intakes of cadmium

Normal exposure to dietary cadmium. Before the dietary intake of any chemical can be estimated, it is essential to know the weight of the diet and the concentration of the chemical in the diet. In some countries the weight and types of food in the average diet are determined each year by extensive surveys among the population. In Great Britain, for example, the weight and composition of an average persons diet are derived from data gathered by the National Food Survey[30] in which the weekly food acquisitions of more than 7000 households are determined. In other countries a hypothetical diet may be designed for a person who is considered likely to have the highest intake of food and, therefore, a high intake of food contaminants. This is done, for example, in New Zealand[11]. The concentrations of the contaminants in the diet may be determined by the analysis of individual foods[28], or by the analysis of groups comprising like foods, for example leafy vegetables[20], or by the analysis of whole diets prepared by institutions such as hospitals[3].

The weight of adult diets used in the estimation of intakes of contaminants in various countries usually lies between about 1.5 and 3.5 kg; this figure refers to the weight of food and beverages consumed in 1 day. The weight taken as representative of total intake can account for at least a 2-fold variation in the estimated contaminant intake from country to country. Furthermore, both the accuracy of the analysis of the diets and the limit of determination of the analytical methodology is critical if intakes are to be reliably determined. If the limit of determination for cadmium was as high as 0.1 mg/kg and findings at or below this level were considered to be 0.1 mg/kg for the purpose of estimation, then the minimum estimated daily intake might be 0.15 mg/kg (0.1 mg/kg × 1.5 kg). Generally, limits of determination for cadmium in food, milk and beverages lie between 0.002 and 0.05 mg/kg depending upon the analytical method and the food matrix; the lower limit of determination is usually achieved for milk and beverages but not for other food. Table 3 presents typical information on the dietary intakes of cadmium in various countries but must be viewed within the constraints outlined above. The WHO/FAO Joint Expert Committee on Food Additives has recommended a provisional tolerable weekly intake (PTWI) for cadmium which, for adults, is 0.4–0.5 mg (0.06–0.07 mg/day), based on a tolerable intake of 1 µg/kg b.wt/day for a 60–70 kg adult[38]. For children the tolerable intake is less. The PTWI concept is akin to the acceptable daily intake (ADI) concept for a chemical which was defined as the 'daily intake which, during an entire lifetime, appears to be without appreciable risk of the basis of all the known facts at the time'[38]. In respect of the PTWI, the word 'provisional' expresses the tentative nature of the evaluation and the word 'tolerable' signifies permissibility rather than acceptability since the intake of the contaminant is unavoidably associated with the consumption of otherwise wholesome and nutritious foods. All of the average daily intakes presented in table 3 are below the PTWI, although four[3,15,23,29] appear to be close to it.

It may be inferred from the data in table 3 and from the meaning of the PTWI that the 'average' consumer in the countries for which data are presented is not endangered by cadmium in the diet. Nevertheless it is prudent to try to keep exposure as low as possible by minimizing the output to the environment from controllable sources.

Abnormal exposure to dietary cadmium. Some individuals have consistently higher intakes of cadmium because they have atypical dietary habits or because the food they eat is produced or grown in areas suffering from cadmium pollution or because of both of these reasons. When such circumstances have been revealed special dietary studies or other estimates of intake have often been undertaken. Where practical, these studies have been coupled with a medical examination of the exposed population and entail, for example, measurements of blood cadmium and B_2-microglobulin excretion. These studies are used to provide information on which a judgement can be made about the risks to health of the exposed population from dietary cadmium. In the UK the dietary intake of cadmium by people consuming food grown in cadmium-polluted areas is generally assessed by means of a duplicate diet study[7]. This involves the collection of exact replicates of all the food consumed in the course of 1 week by a sample of individuals from the exposed population. These studies are difficult and costly to undertake, and rely heavily on the ability of the participants to ensure that there will be no discrepancy between the amount of food they actually eat and the amount of food claimed to be exact replicates of their diet. Practical experience in the UK shows that the average weight of duplicate diets is about 25% less than would be expected on basis of data gathered from the National Food Survey. Instances of severe cadmium pollution are rare although recent investigations have been made at the village of Shipham in Somerset, England[34]. Some samples of Shipham soil contained more than 100 mg/kg of cadmium, and some vegetable samples contained more than 1 mg/kg of cadmium. The cadmium intakes of the study sample as determined by a duplicate diet study were about double the estimated UK intake and some individuals exceeded the PTWI for cadmium. There was no evidence from the medical checks that any of the present residents of Shipham had suffered adverse health effects related to cadmium.

Estimation of cadmium intakes by individuals who have atypical dietary habits is extremely difficult because, in contrast to people consuming food grown on contaminated land, the individuals cannot be easily identified. For example, regular consumption of liver will increase the dietary intake of cadmium, but individuals who consume abnormal amounts of liver are not easy to identify by, for example, their place of residence. In these circumstances it is usual to estimate intake by assuming a high consumption of the food and multiplying this by the average concentration of cadmium (or any other contaminant) in the food. Investigations in the UK have shown[7] that high consumptions of individual foods may be related to the average consumption by the consuming population using simple equations. Thus the 90th percentile consumption (y in g/week) of a food has been found to be related to the average consumption (x) by:

$$y = 1.6\,x + 60.5$$

If this relationship holds widely it means that, once an extreme consumption is defined in terms of the percentile of the consuming population, and the average consumption of the food is known, then a high intake of the contaminant may be estimated using data on the concentration of cadmium in the food and the calculated extreme consumption. More recent investigations by the author[33*] indicate that the frequency distribution of consumption of individual foods for a wide range of foods is approximately lognormal. The logarithmic standard deviation of the distributions are similar for a wide range of foods as are the ratios of the arithmetic to geometric mean for each distribution. This finding explains to some extent the relationships described by Coomes et al.[7]. For example the logarithmic mean consumption of liver in the UK is equivalent to 0.1 kg/week and the logarithmic standard deviation of the frequency distribution is 0.257. Using these data it may be shown that the 97.5th percentile consumption in any one week is 0.32 kg. The mean cadmium content of liver sold in the UK is about 0.1 mg/kg, so that cadmium intakes from liver in the UK will rarely regularly exceed 0.03 mg/week (0.32 mg × 0.1 mg/kg = 0.03 mg), which is well within tolerable limits. Obviously, more liver may be consumed in other countries where the population has different dietary habits and similar differences will apply to other foods.

Table 3. Typical dietary intakes of cadmium

Country	Intake (mg/week)	Reference
Germany	0.40	3
Germany	0.20[a]	35
Poland	0.13[a]	23
Japan	0.27	28
New Zealand	0.11	11
Australia	0.15	8
Belgium	0.35	15
Denmark	0.21	24
Italy	0.38	29
USA	0.23	20
Great Britain	< 0.15	25

[a] Intakes by children.

Conclusions

In general, the concentrations of cadmium in food are low although some foods of minor dietary importance, such as shellfish or kidney, often contain cadmium concentrations greater than 0.5 mg/kg. The concentration of cadmium in many foods can be increased due to environmental cadmium pollution. At present, dietary intakes of cadmium in most countries are generally less than the PTWI but emissions of cadmium into the environment are continuing. While control of cadmium emissions may decrease the rate of emission, the dispersion of cadmium into the environment will inevitably continue as long as emissions take place. For this reason there is a clear need for continued monitoring of cadmium in food and the environment, coupled with research into the effects on man of low level exposure to cadmium. This research should take into account other important sources of exposure to cadmium. There is, for example, very strong evidence[13] to show that the total body burden of cadmium and the concentration of cadmium in the liver and kidneys of smokers is significantly higher than for non-smokers.

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