

Risk Assessment Studies

Report No. 18

Chemical Hazard Evaluation

**DIETARY EXPOSURE TO LEAD
OF
SECONDARY SCHOOL STUDENTS**

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Food and Environmental Hygiene Department

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Abstract

This study estimated the dietary exposure to lead of the secondary school students in Hong Kong, assessed the associated health risk and explored measures to reduce the lead exposure.

Dietary exposure to lead was estimated by using the local food consumption data obtained in secondary school students in 2000 and the concentrations of lead in food samples taken from the local market. Laboratory analysis for lead was conducted by the Food Research Laboratory of the Food and Environmental Hygiene Department.

The dietary exposures to lead for average and high consumers of secondary school students were 1.98 and 5.09 $\mu\text{g/kg bw/week}$ respectively. Both levels were well below the Provisional Tolerable Weekly Intakes (PTWI) of 25 $\mu\text{g/kg bw/week}$ for lead. It can be concluded that both the average and high consumers of secondary school students are unlikely to experience major toxicological effects of lead.

The results also showed that the food group “vegetables”, particularly leafy vegetables, was identified as the main dietary source of lead. Surface contaminated lead could be effectively removed by thoroughly soaking and washing of leafy vegetables in water. Lime preserved egg and oysters were found to contain high concentration of lead and they may be significant dietary sources of lead if they are consumed in large amount.

Because of the ubiquitous nature of lead, low levels of lead in foods may be unavoidable. Food trade is recommended to observe good agricultural and manufacturing practices to minimise lead contamination of foods. Members of the public are advised to wash vegetables thoroughly before cooking and have a balanced diet to avoid excessive exposure to lead from a small range of food items.

Dietary Exposure to Lead of Secondary School Students

OBJECTIVE

This study aims to determine the dietary exposure to lead by the secondary school students in Hong Kong, to assess the associated health risk and to explore measures to reduce dietary exposure to lead.

BACKGROUND

2. The Food and Environmental Hygiene Department (FEHD) has conducted a study on “Dietary Exposure to Heavy Metals of Secondary School Students” in 2002, in which three heavy metals, namely mercury, arsenic and cadmium were studied, and a follow-up study on “Dietary Exposure to Mercury of Secondary School Students” in 2004. In view of the adverse effect of lead and public concern, that food is regarded as the main source of exposure and that there is a lack of local exposure data, there is a need to conduct a study to examine the local situation.

3. Lead is a naturally occurring toxic heavy metal which is ubiquitous in the environment as a pollutant. It has widespread industrial uses such as

battery production, preparation of paints and petrol, etc. Lead can be present in food as a result of environmental pollution or unintentional contamination during food processing, handling and packaging.

Sources of Lead

4. Lead may enter the environment at any point during mining, smelting, processing, recycling or disposal. Lead is also used in solder applied to water distribution pipes and to seam of cans used to store foods, in bottle closures for alcoholic beverages and in ceramic glazes and crystal tableware, although some of these usages are fading out. Its uses would result in increase of the lead levels in soil, water and air. In some countries where leaded petrol is still used, the major air emission of lead is from combustion of petrol. Atmospheric lead is also a major source of lead in household dust.¹

5. Lead is present in soils and is transferred to food crops growing on soil. Lead present in air may also deposit on leafy vegetables. Therefore, cereals and vegetables may contain high level of lead. Aquatic food animals may also accumulate lead from contaminated waters and sediments. Shellfish was reported to contain a higher level of lead than fish since the chemical tends to bioconcentrate more in shellfish than in fish. For meat and meat products, since lead accumulates more in the offal, higher level of lead would be present in offal than in the meat tissues.

6. Traditionally, lead compounds have been used for processing lime preserved egg, and therefore a high lead level was detected in the lime preserved egg.

Toxicity

Metabolism

7. After ingestion, the absorption rate of lead ranges from 3% to 80% whereas the typical absorption rates of dietary lead in adults and infants are 10% and 50%, respectively. After absorption, lead is initially distributed to soft tissues throughout the body via blood, and then deposited in bone. Lead is excreted through the kidney and to a lesser extent in the bile while non-absorbed dietary lead is excreted in the faeces. Organic lead may be metabolised to inorganic lead. The concentration of lead in blood is commonly used as biomarker of exposure. Other markers include bone lead concentration, urinary concentration and dentine lead.²

Toxicity and Carcinogenicity

8. Lead is a classical chronic toxic chemical. Lead may cause damages to kidneys, the cardiovascular, immune, haematopoietic, central nervous and reproductive systems. Short term exposure to high level of lead can cause gastrointestinal distress, anaemia, encephalopathy and death.³ The most critical effect of low-level exposure is retarded cognitive and intellectual development in children. Infant, young children and the foetus are more

sensitive to toxic effects of lead, especially the damages to central nervous system.⁴

9. The International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) has evaluated the carcinogenicity of lead and lead compounds. IARC considered that there are inadequate evidence for carcinogenicity of both inorganic lead and organolead compounds in human, sufficient evidence for inorganic lead compounds in experimental animals and inadequate evidence for organolead compounds in experimental animals. It classified lead and inorganic lead compounds as Group 2B agent, and organolead compounds as Group 3 agent.

Level of Safe Intake of Lead

10. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has established a provisional tolerable weekly intake (PTWI) of 25µg/kg bw/week for lead.

11. PTWI is an estimate of the amount of a contaminant that can be ingested over a lifetime without appreciable risk. An intake above the PTWI does not automatically mean that health is at risk. Transient excursion above the PTWI would have no health consequences provided that the average intake over long period is not exceeded as the emphasis of PTWI is a lifetime exposure.

Sources of Human Exposure

12. Lead exposure can occur through food and water as well as soil and air and the relative contributions from individual sources may depend on life-style and socioeconomic status. It was reported that the main sources of exposure for an adult are food (ranged from 0.4 $\mu\text{g/kg bw/week}$ to 10.1 $\mu\text{g/kg bw/week}$) and water (ranged from 0.23 $\mu\text{g/kg bw/week}$ to 0.35 $\mu\text{g/kg bw/week}$).

13. Airborne lead may contribute significantly to exposure, depending on various factors such as tobacco smoking, occupation and proximity to sources, which may vary considerably.¹ For smokers who smoke 20 cigarettes daily, an additional exposure of lead from cigarette smoking was estimated to be 0.28 $\mu\text{g/kg bw/week}$.

14. The main potential sources of exposure to lead in children are food, air, water and dust or soil. It has been reported that the dietary intakes of children (ranged from 0.6 – 30 $\mu\text{g/kg bw/week}$) could be two to three times that of adults.

15. In other dietary exposures studies such as those conducted in the UK and Mainland China, cereals and vegetables were found to be the main dietary sources of lead, which contributed 31% to 40% of total dietary exposure for cereals, and 23% to 35% of total dietary exposure for vegetables.^{5,6}

SCOPE OF STUDY

16. To estimate the dietary exposure to lead, this study covered six major food groups, namely (i) cereals and cereal products, (ii) vegetables, (iii) fruits, (iv) meat, poultry, egg and their products, (v) seafood, (vi) milk and dairy products. The selection was based on the occurrence of lead in those food groups and the consumption patterns.

17. As leafy vegetable was reported to be contaminated with lead through adherence of the lead present in air, the study also explored the measures which can be taken at the consumer level.

METHODOLOGY

Dietary Exposure

Food Consumption Data

18. The food consumption data in this report were extracted from the Food Consumption Survey conducted in local secondary school students in 2000 by FEHD. In the survey, a stratified three-stage sampling plan was used, with a sampling frame of 472 secondary schools and more than 380,000 students, covering almost all the local secondary schools. A total of 967 students from 27 schools participated in the survey yielding a response rate of 77% at the

school level and 96% at the student level. The mean weight of the participated students was 52.0 kg.⁷

Sampling Plan

19. Food samples were taken from the local market according to the six food groups as mentioned above. Food items were selected so as to match those in the Food Consumption Survey as well as those with likely occurrence of lead. Three samples of each food item from different sources were taken for analysis.

Laboratory Analysis

20. Laboratory analysis was done by the Food Research Laboratory (FRL) of FEHD. The analysis was conducted mainly in the form of “composite sample”. Samples collected randomly from the three different sources were mixed and homogenised. The composite sample was then digested with concentrated acid, followed by determination of lead using inductively coupled plasma mass spectrometry (ICP-MS). The limit of detection (LOD) was 0.6 µg/kg.

21. When the analytical value was below the LOD, the true value could be anywhere between zero and the LOD. The treatment for these results was particularly important when a large percentage of the analytical results of a particular food group were below LOD. While it may not be appropriate to

assume a zero concentration for all the samples with analytical values below LOD, assigning the non-detects the value of LOD would, however, grossly overestimate the dietary intake. A value of 1/2-LOD was assigned to all results below LOD in this study. Since the levels of contaminants in food, including lead, usually follows a log-normal distribution, assigning a value of 1/2 LOD to all non-detected levels is considered as a conservative approach for food groups in which the majority of food items have levels below the LOD.

Dietary Exposures to Lead

22. Dietary exposure from individual food item was obtained by combining the consumption data and the concentration of individual food items. Daily dietary exposure was multiplied by seven to obtain a weekly exposure level. Total exposure for each student was obtained by summing exposures from all food items. The mean and 95th percentile of the weekly exposure levels were used to represent the average dietary exposure and the exposure for high consumers respectively.

23. The estimated weekly exposure levels were then compared with the PTWI as established by JECFA.

Reduction of Level of Lead in Leafy Vegetables

Sampling and Treatment of Samples

24. Two varieties of leafy vegetables were selected based on the findings of the initial results. Three samples of each variety from different sources were taken for analysis. The six leafy vegetables samples were subject to soaking in water for 30 minutes, washed in running water for 1 minute, and then cooked in boiling water for 3 minutes. The levels of lead in the samples were determined at different stages: (i) raw and as sold, (ii) after soaking and washing, and (iii) after boiling.

25. Another sets of bak choi and flowering cabbages samples were also obtained and they were subject to cooking in boiling water without prior washing or soaking. The levels of lead were determined (i) raw and as sold and (ii) after boiling.

RESULTS

Food Consumption Data

26. Food consumption data for the six food groups are given in Table 1.

Table 1: Food Consumption for Secondary School Students

Food groups	Mean consumption (g/day)
Cereal and cereal products	478.0
Vegetables	295.3
Fruits	309.1
Meat, poultry, egg and their products	189.4
Seafood	122.4
Milk and dairy products	143.2

Concentration of Lead in Food

27. A total of 345 food samples were taken and combined into composite samples and 117 analyses were done. The results are given in Table 2.

Table 2: Number of Samples Taken and Median Concentrations for Lead in Six Food Groups

Food groups	Number of samples	% of samples below LOD	Median concentration (µg/kg)
Cereal and cereal products	45	93.3	<LOD*
Vegetables	81	3.7	14.2
Fruits	21	71.4	<LOD *
Meat, poultry, egg and their products	99	63.6	<LOD *
Seafood	84	10.7	7.6
Milk and dairy products	15	100.0	<LOD *

(* a value of 1/2 LOD was assigned, i.e. 0.3µg/kg)

28. Lead was detected in most of the samples of the two food groups “vegetables” and “seafood”. For the other food groups except “milk and dairy products”, lead was detected at low levels in most of samples. As for “milk and dairy products”, lead was not detected in all the samples. The distribution curves of lead concentration in the six food groups are given in Annex.

Dietary Exposures to Lead

Average Secondary School Students

29. The dietary exposure to lead for average secondary school students was estimated to be **1.98 µg/kg bw/week**. The main dietary source of lead was “vegetables” which contributed to 57.7% of the total exposure. This was followed by “meat, poultry, egg and their products” and “seafood” which

contributed 21.1% and 15.4% of the total exposure respectively. Dietary exposures to lead from different food groups are shown in Table 3.

Table 3: Estimated Dietary Exposure to Lead for Average Secondary School Students

Food groups	Dietary exposure to lead in µg/kg bw/week (% contribution)
Cereal and cereal products	0.03 (1.7%)
Vegetables	1.14 (57.7%)
Fruits	0.07 (3.7%)
Meat, poultry, egg and their products	0.42 (21.1%)
Seafood	0.31 (15.4%)
Milk and dairy products	0.01 (0.3%)
Total	1.98 (100%)

(*Figures may not add up to total due to rounding)

High Consumers

30. Further analysis was undertaken to estimate the risk that high consumers might be exposed to. The 95th percentile exposure level of the secondary school students was used to represent the dietary exposure to lead for high consumers and was estimated to be 5.09 µg/kg bw/week. (Table 4)

Table 4: Comparison between PTWI Established by JECFA and Dietary Exposures to Lead for Average Secondary School Students and High Consumers

JECFA PTWI (µg/kg bw/week)	Exposure (µg/kg bw/week) (% of PTWI)	
	Average secondary school students	High Consumers
25	1.98 (8%)	5.09 (20%)

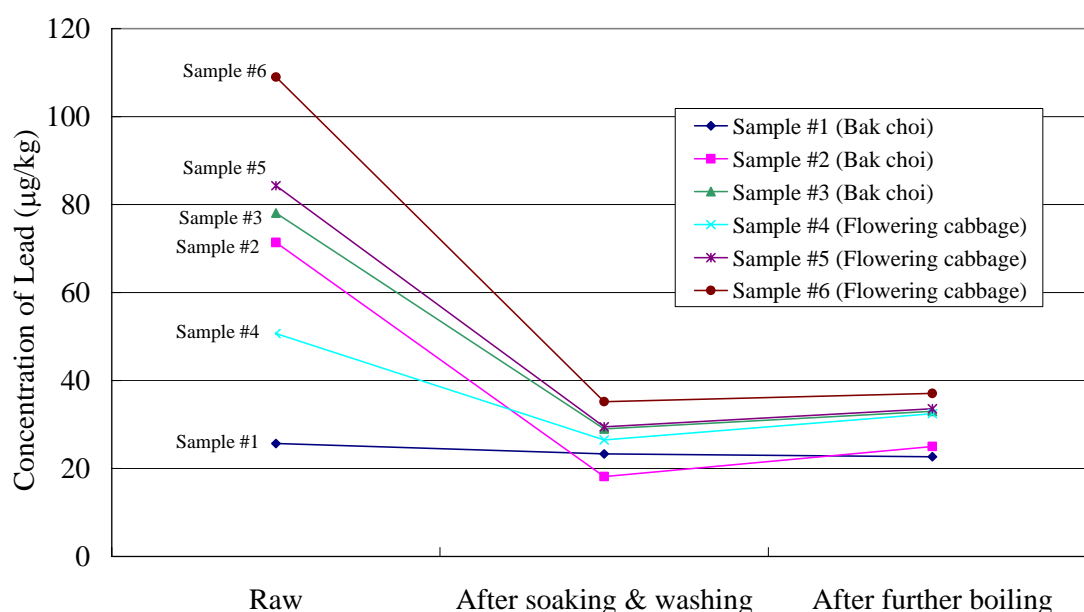
Reduction of level of lead in leafy vegetables

31. The levels of lead in the leafy vegetable samples which had been subject to soaking, washing, and/ or boiling in water are given in Table 5 and Figure 1. For comparison, the levels of lead in samples which subjected to boiling in water only are given in Table 6.

Table 5: Change in Concentration of Lead in Leafy Vegetables after Soaking, Washing and Boiling

Samples	Lead concentration (µg/kg)		
	Raw	After soaking & washing (% reduction compare with raw)	After further boiling (% reduction compare with raw)
Bak choi			
Sample #1	26	23 (-12%)	23 (-12%)
Sample #2	71	18 (-75%)	25 (-65%)
Sample #3	78	29 (-63%)	33 (-58%)
Flowering cabbage			
Sample #4	51	27 (-47%)	33 (-35%)
Sample #5	84	30 (-64%)	34 (-60%)
Sample #6	110	35 (-68%)	37 (-66%)
<i>Mean</i>	70	27 (-61%)	31 (-56%)

Figure 1: Change in Concentration of Lead in Leafy Vegetables After Soaking, Washing and Boiling



32. The mean concentration of lead in the leafy vegetables decreased from $70 \mu\text{g/kg}$ to $27 \mu\text{g/kg}$ (61% reduction) after soaking and washing and to $31 \mu\text{g/kg}$ after further boiling. The mean percentage reduction in lead concentration after soaking, washing and boiling in water was 56% (range: 12% to 66%). However, the mean concentration of lead in another set of samples of leafy vegetables decreased from $170 \mu\text{g/kg}$ to $150 \mu\text{g/kg}$ after boiling in water only (without soaking and washing), and this amounted to 12% of reduction in concentration (range: 7% to 15%).

Table 6: Change in Concentration of Lead in Leafy Vegetables after Boiling Only

Samples	Lead concentration ($\mu\text{g/kg}$)		% of reduction after boiling only
	Raw	After boiling only	
Bak choy	140	130	-7%
Flowering cabbage	200	170	-15%
<i>Mean</i>	<i>170</i>	<i>150</i>	<i>-12%</i>

DISCUSSION

Dietary Exposure

33. The dietary exposure to lead for an average secondary school student was estimated to be $1.98 \mu\text{g/kg bw/week}$ while that for the high consumer was $5.09 \mu\text{g/kg bw/week}$. These exposures amounted to 8% and 20% of the PTWI respectively. Exposures to lead for an average secondary school and the high consumer were both well below the PTWI established by JECFA.

34. Therefore, the dietary exposure estimates suggested that the average secondary school students and high consumers were unlikely to experience major undesirable health effects of lead.

35. In our study, the main dietary source of lead was “vegetables” which contributed to 58% of the total exposure, and leafy vegetables are particularly

significant source. In other dietary exposures studies such as those conducted in the UK and Mainland China, cereals were identified as the main contributor (31 to 40% of dietary exposure) and vegetables ranked second (23% to 35% of dietary exposure). In our study, cereal accounted for only 2% of dietary exposure. This discrepancy is mainly due to the lower levels of lead detected in cereal and cereal products in our study as compared with those detected in studies in the UK and Mainland China.

36. Following “vegetables”, the food group “meat, poultry, egg and their products” ranked second in terms of contribution to dietary exposure to lead and this was followed by “seafood” (21% and 15% of dietary lead exposures respectively).

37. The food group “meat, poultry, egg and their products” was further analysed and the lead level of more than 60% of the samples in the food group were below LOD. However, lime preserved eggs were found to have the highest level of lead (mean: 1.2 mg/kg). This food item alone accounted for 17% of total dietary exposure to lead, or 79% of the contribution by this food group in total. Excluding lime preserved egg, dietary exposure to lead from other foods in the group was only 0.09 µg/kg bw/week, or 5% of total dietary exposure.

Lime Preserved Eggs

38. It was noted that there are different patterns of lead levels in lime preserved eggs. The levels in one composite sample and one individual sample were 1.8 mg/kg and 1.5 mg/kg respectively, whereas those in another two individual samples were 0.006 mg/kg and 0.001 mg/kg respectively. Traditionally, lead oxide has been used in the production of lime preserved egg to accelerate the coagulation process⁸, and a high lead content may be found in such lime preserved eggs. Alternate methods are available which use copper or zinc compounds instead of lead oxide.⁹ These alternative methods may result in lower levels of lead in the finished products than those prepared by the traditional methods of using lead oxide. It has been reported that the levels of copper and zinc in the finished products by using the alternative methods were as high as 13 mg/kg¹⁰ and 19 mg/kg¹¹ respectively. Copper and zinc are essential micronutrients and with such levels in lime preserved eggs and consumption pattern, toxicity of copper and zinc from lime preserved egg is not expected.

Oysters

39. Following lime preserved eggs, oysters were found to have the second highest level of lead (mean: 0.29 mg/kg). Exposure to lead from oysters accounted for 8% of total dietary exposure, or half of the contribution by the food group “seafood”.

Reduction of Lead in Leafy Vegetables

40. Leafy vegetables were found to be the major contributor (45%) to the total exposure to lead. It has been reported in literature that lead in plants may be resulted from both deposition from air leading to surface contamination and uptake from the soil.

41. Our findings suggested that a significant portion (more than half) of lead could be removed from the leafy vegetables by soaking and washing in water. Cooking in boiling water alone is not as effective in reducing the level of lead as compared with soaking and washing, since the process of soaking and washing in water could remove the surface contamination of leafy vegetables. It was found that the level of lead increased slightly after further boiling and it may be due to the change in moisture content during processing.

International Comparison

42. Dietary exposures to lead in 1990s in other studies were reviewed and were summarised in Table 7.

43. It can be seen that the dietary exposure estimated in our study compares favourably to exposure estimates obtained from other studies. However, direct comparison of the data has to be done with caution due to the differences in time when the studies were carried out, research methodology, food group

categorisation, methods of collection of consumption data, methods of contaminant analysis and methods of treating results below detection limits.

Table 7: A Comparison of Average Weekly Exposure of Lead

Country / Region	Average weekly dietary exposure (µg/ kg bw/week)
Mainland China	10.1
France	8.3
Australia	4.9
New Zealand	3.3
UK	3.3
Canada	2.4
Hong Kong	2.0*
Finland	1.4
US	0.4

* The exposure data in Hong Kong is extracted from our current study.

Other Sources of Lead Exposure

44. Apart from food, tobacco smoke, air and water may also contribute significantly to lead exposure. For smokers who smoke 20 cigarettes daily, an additional exposure of lead from cigarette smoking was estimated to be 0.28 µg/kg bw/week, and this accounted for an extra of about 15% of our current dietary exposure.

45. According to data from the Environmental Protection Department and the Water Supplies Department, the annual average ambient levels of lead in air ranged from 43 – 56 ng/m³ in 2002¹² and the average level of lead in our drinking water was <0.003 mg/L in water for the period of October 2003 – September 2004¹³. Assuming that the respiratory volume in a 60-kg adult is 20 m³/day and volume of water consumed is 2 litre/day respectively, exposure to lead from air was estimated to be 0.10 – 0.13 µg/kg bw/week and that from drinking water was estimated to be < 0.7 µg/kg bw/week. Hence, the main source of exposure to lead was food (over 70% of exposure for non-smokers). Taking exposure from water into account, exposure to lead was still far below the PTWI.

Environmental Measures

46. To reduce the human exposure to lead globally, the use of lead and lead compounds should be reduced and the lead-containing emissions should be minimised. The restrictions on industrial emission and on the use of leaded petrol would result in lower lead levels in air. Although it is not targeted specifically at food, such restrictions have also contributed to declining lead levels in food. For example, in the US, the use of lead-containing petrol additives has been reduced since 1980s, and a marked decrease (about 65% reduction) in lead intake from food in 2-year-old infants over a four-year period from 1986 to 1990 was observed. Other measures, such as restriction of the use of lead-soldered cans, control of lead levels in water, reduction of leaching

from lead-containing vessels or restriction of their use for storing food, could also reduce the lead exposure from food.

47. In Hong Kong, the sale and supply of leaded petrol was banned since April 1999 and the ambient lead concentrations remain at low levels.

48. To reduce lead exposure from food effectively, the Codex Committee on Food Additives and Contaminants (CCFAC) has developed a “Code of Practice for the Prevention and Reduction of Lead Contamination in Foods” and this set of guidelines has been adopted in 2004. A number of measures to reduce lead exposures are included in the guidelines, regarding agricultural, manufacturing and consumer practices.

LIMITATIONS

49. The methodology for collection of food consumption data may influence the accuracy of the estimates on dietary exposure. In the Food Consumption Survey, the food consumption pattern of secondary school students was collected using a food frequency questionnaire. Although the food frequency questionnaire was very comprehensive, it was not possible to cover every single food item, some of which might be relevant to lead exposure. Furthermore, only the data of consumption pattern for secondary school students is available. To produce more accurate estimates, FEHD is in the

process of conducting a population-based food consumption survey which would allow more comprehensive exposure studies to be conducted in the future.

50. Three samples for each food item were taken combined into one composite sample for laboratory analysis. Although more than 300 samples were taken in the study, increasing the number of sample for each food item for laboratory analysis could provide a more precise estimate of the mean lead concentration for the particular food item. However, the number of samples taken have to be balanced with the required resources and number of food items to be included.

51. Lead exposures from individual sources may vary greatly, which depends on the life-style and socioeconomic status. This study mainly focused on lead exposure from food and sources like cigarette smoking, water and air were addressed. However, other sources of exposures, such as those from dust and soil, were not covered in the present study.

CONCLUSIONS AND RECOMMENDATIONS

52. The dietary exposures to lead were 1.98 and 5.09 $\mu\text{g/kg bw/week}$ for average secondary school students and high consumers respectively. They were all well below the PTWI established by JECFA. It can be concluded that

both the average and high consumers among secondary school students are unlikely to experience major toxicological effects of lead.

53. The food group “vegetables” was identified as the main dietary source of lead and leafy vegetables are particularly important. The level of lead in leafy vegetables can be effectively reduced by thorough soaking and washing in water before cooking.

54. Lime preserved eggs and oysters were found to contain high concentration of lead and they may be significant dietary sources of lead if they are consumed in large amount.

55. Food is recognised as the major source of lead exposure. Because of the ubiquitous nature of lead in the modern industrial world, low levels of lead in foods may be unavoidable. However, the food trade is advised to observe good agricultural and manufacturing practices to minimise lead contamination of foods, such as avoid using lead compounds as pesticides or for food production.

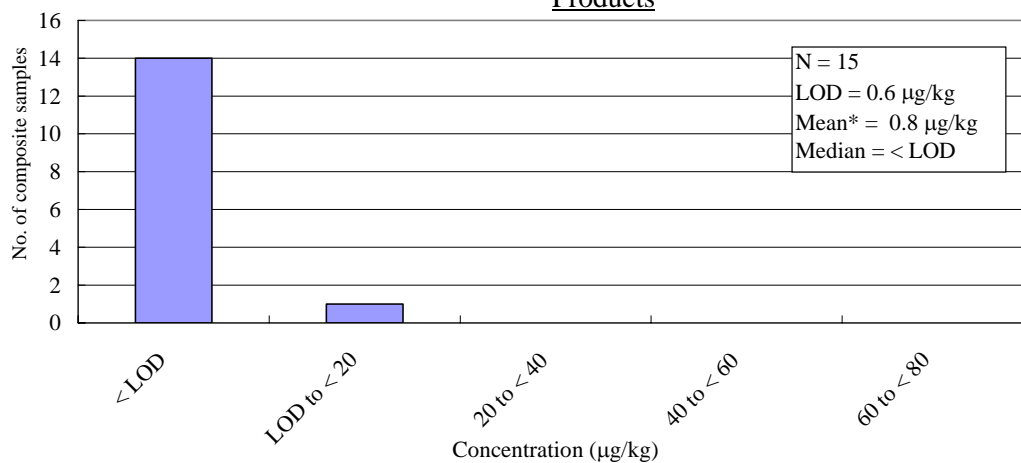
56. The public is advised to soak and wash vegetables thoroughly to remove dust and soil and to reduce the level of lead. Before preparing food, washing hands would also help remove any lead-contaminated dust or soil from hands.

57. A balanced diet is essential to avoid excessive exposure to lead from a small range of food items.

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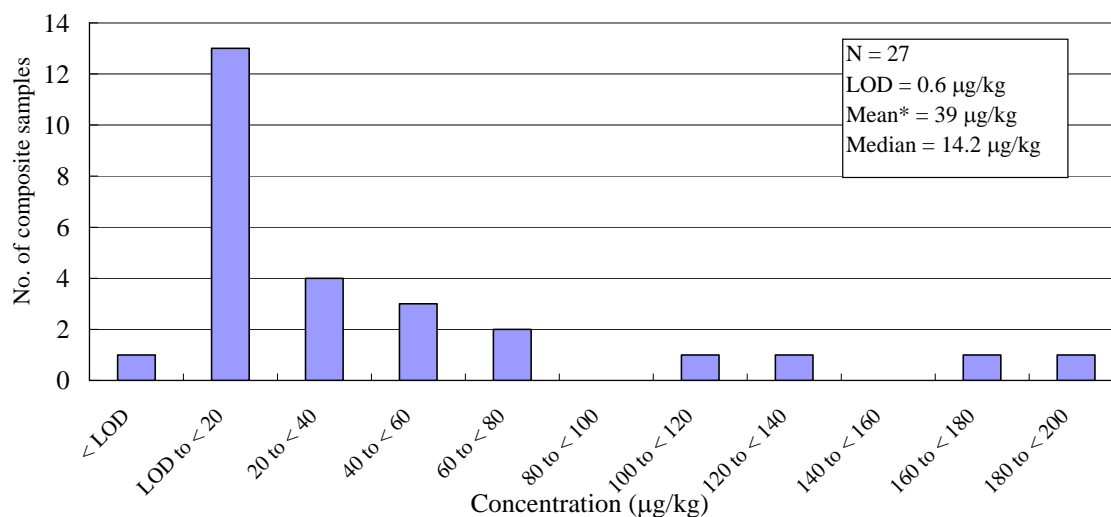
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Figure A: Distribution Curve of Lead Concentration in Cereal and Cereal Products



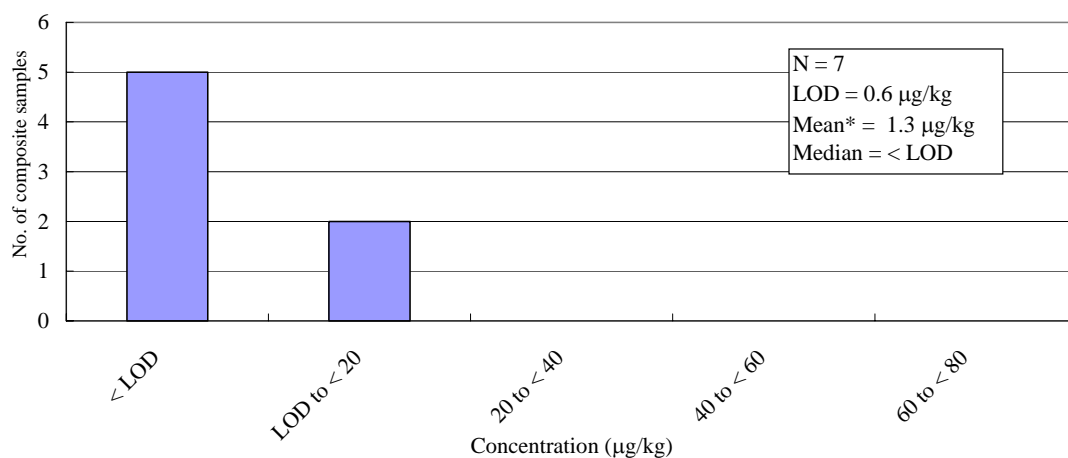
* For calculating the mean, a value of 1/2LOD was assumed for those values below LOD.

Figure B: Distribution Curve of Lead Concentration in Vegetables



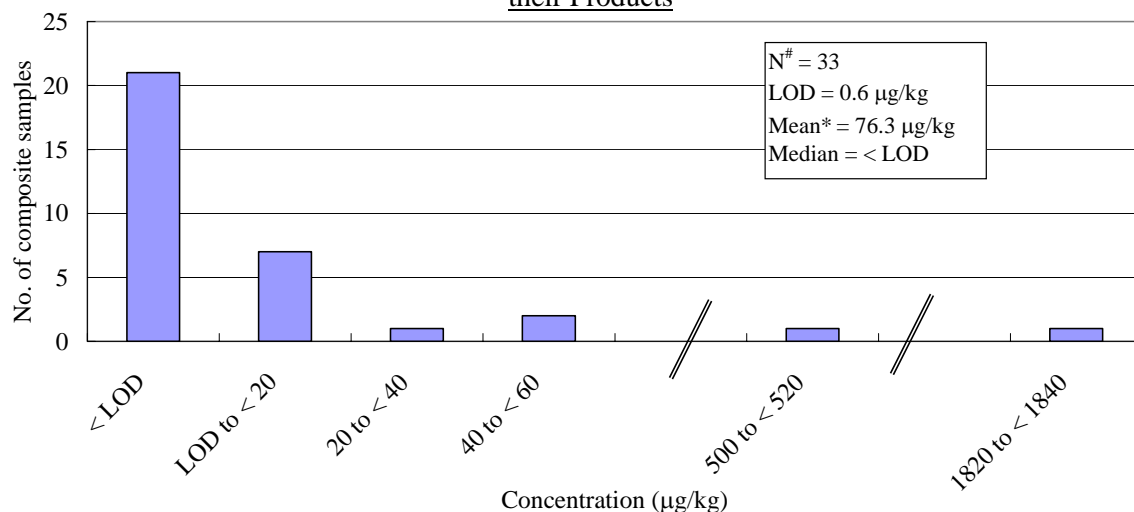
* For calculating the mean, a value of 1/2LOD was assumed for those values below LOD.

Figure C: Distribution Curve of Lead Concentration in Fruits



* For calculating the mean, a value of 1/2LOD was assumed for those values below LOD.

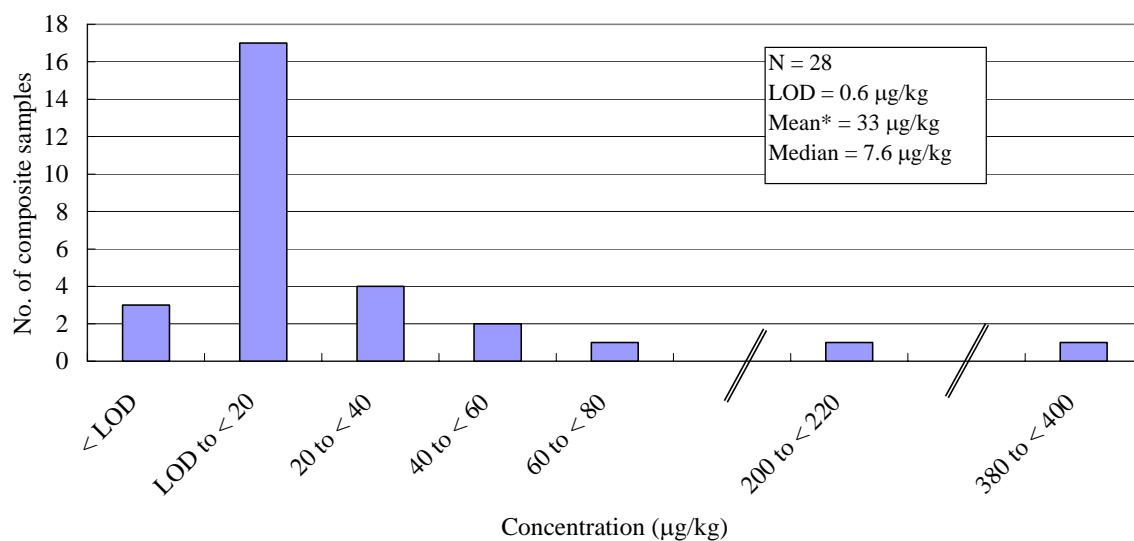
Figure D: Distribution Curve of Lead Concentration in Meat, Poultry, Egg and their Products



For graphical presentation, mean of 3 individual samples of lime preserved eggs was assumed as the value for a composite sample

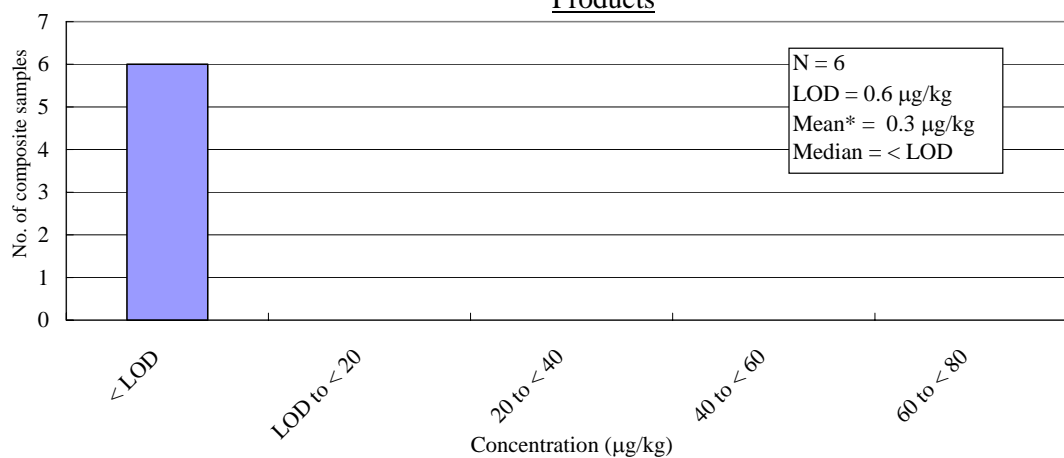
* For calculating the mean, a value of 1/2LOD was assumed for those values below LOD.

Figure E: Distribution Curve of Lead Concentration in Seafood



* For calculating the mean, a value of 1/2LOD was assumed for those values below LOD.

Figure F: Distribution Curve of Lead Concentration in Milk and Dairy Products



* For calculating the mean, a value of 1/2LOD was assumed for those values below LOD.