Estimating Cadmium Absorption Rate in Digestive Organs Calculated from Information of Studies on Cadmium Conducted in Japan

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Abstract: The absorption rate of cadmium (Cd) in the digestive organs is reported to be 0.5–8% in Friberg’s textbook. This value was obtained from experimental studies. The object of the present study is to obtain the value from the Cd intake amount by ingestion, the Cd absorption amount by respiration and smoking, and the total Cd absorption amount calculated from the Cd accumulation amount in organs reported in articles including not only experimental but also epidemiologic studies conducted in Japan. The oral intake amounts of Cd in Japan were obtained from a published article to be 48 μg/day for males in the 1970s. The total Cd absorption amount that was calculated from the Cd accumulation amount in organs of 223 male subjects autopsied following sudden death was found to be 6.8 μg/day for male adults in the 1970s. The Cd exposure before the 1970s reflected the Cd absorption amount calculated from the Cd accumulation amount in the 1970s. The Cd absorption amount by respiration and smoking for males in the 1960s was 1.0 μg/day, and the difference of 5.8 μg/day between the above two corresponds to the Cd absorption amount in digestive organs before the 1970s. The rice intake amount for Japanese in 1955–1965 was reported to be about 1.4 times as much as that in 1975. Therefore the Cd absorption rate in digestive organs was estimated to be about 10% from these values, assuming that most of the change in Cd intake from food is derived from the amount of rice eaten in Japan. This value is somewhat greater than the values published in the literature.

Key words: smoking, food, cadmium absorption amount, cadmium accumulation amount in organs, cadmium absorption rate in digestive organs.

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Introduction

The major sources of exposure to cadmium (Cd) are environmental media, i.e. air, water, and soil. Food, drink, and tobacco produced in the environment are exposure sources of Cd in a narrow sense. Cd is absorbed via ingestion and respiratory routes. Cd in food and drinking water is ingested orally and absorbed in the digestive organs, and Cd in air, dust and cigarette smoke is inhaled and absorbed in the respiratory organs. Most of the total Cd absorption amount comes from eating and smoking [1, 2]. To estimate exposure levels of Cd, it is effective to obtain the concentrations of Cd in the above substances. The Cd intake amount by ingestion, the Cd absorption amount by respiration and smoking, and the total Cd absorption amount calculated from Cd accumulation amount in organs have been shown in many articles as indicators of the Cd body burden.

The absorption rate of Cd in the digestive organs is an important parameter to predict Cd absorption amount calculated from Cd intake amount by ingestion. The parameter is reported to be 0.5 – 8% in Friberg’s textbook [1], which was obtained from experimental studies. We can find few epidemiologic studies which have reported the values. The object of the present study is to obtain the absorption rate of Cd in the digestive organs from the Cd intake amount by ingestion, the Cd absorption amount by respiration and smoking, and the total Cd absorption amount calculated from the Cd accumulation amount in organs in articles including not only experimental but also epidemiologic studies conducted in Japan. These values from studies conducted in Japan were obtained chronologically, because the socioeconomic environment in Japan has been changing remarkably for over several decades. We can find few review articles which have reported several indicators of the Cd body burden together chronologically.

Materials and Methods

The Cd intake amount by ingestion, the Cd absorption amount by respiration and smoking, and the total Cd absorption amount calculated from Cd accumulation amount in organs were taken from articles and calculated by using methods published in articles and conducted in Japan.

*Cd intake from food*

We collected information on Cd intake from food in Japan. The Cd intake amount varied by time, making it necessary to take into account the variation.

*Cd absorption from smoking*

Cd absorption from smoking cigarettes in Japan was reported [3], and the amounts of Cd
absorption from smoking were obtained in the present study by using the method in the article [3].

The absorption rate of Cd in airways was concluded to be $25 - 50\% \left[1, 2\right]$, and this value is used in the present study as $a = 25 - 50\% \left(37.5 \pm 12.5\%\right)$. The proportion of the amount of Cd in the main stream of cigarette smoke to the amount of Cd in one cigarette as determined by Szadkowski[4]and Elinder[5]was employed in the present study as $i = 10\%$.

The amount of Cd absorbed from smoking is the product of the Cd inhaled amount by the absorption rate of Cd in the airways.

The amounts of Cd absorbed and inhaled from smoking varied with time, so the variation was taken into consideration. The mean amount of Cd in one cigarette sold in Japan $y_i$ is obtained as:

$$y_i = s_i \cdot \left| z_i \cdot m_i + z_r \cdot (1 - m_i) \right| + (1 - s_i) \cdot z_A,$$  \hspace{1cm} (1)

where $s_i$ is the market share in Japan for cigarettes produced in Japan, $m_i$ is the proportion of tobacco leaves harvested in Japan and used in cigarettes produced and sold in Japan, and $z_A$ and $z_r$ are the amounts of Cd in one cigarette produced in the USA and countries other than Japan, respectively. In particular, $z_r$ indicates the amount of Cd in one cigarette made from 100% tobacco leaves harvested in Japan.

Under the assumption that the number of cigarettes smoked by adult smokers do not vary according to gender and age, the mean amount of Cd absorbed in one day for an adult resident in Japan by gender is calculated as:

$$b_m = y_i \cdot c \cdot i \cdot a \cdot r_m \cdot \left| 365.25 \cdot (p_m \cdot r_m + p_r \cdot r_r) \right|,$$

$$b_f = y_i \cdot c \cdot i \cdot a \cdot r_f \cdot \left| 365.25 \cdot (p_m \cdot r_m + p_r \cdot r_r) \right|,$$ \hspace{1cm} (2)

where $c$ is the total number of cigarettes sold in one year in Japan, $r$ is the smoking rate in Japan, $p$ is the adult population, and subscripts ‘m’ and ‘f’ indicate male and female, respectively. The values $b_m$ and $b_f$ are the means for all adult residents in Japan including not only smokers but also nonsmokers. The values are calculated ignoring smoking by juveniles.

**Respiratory absorption of Cd**

Information on the amount of Cd absorption by respiration was collected from published reports.

**Calculation of Cd absorption from Cd accumulation in organs**

Biological half-time (BHT) of Cd was investigated using Cd accumulation data in organs and tissues of Japanese residents who underwent autopsy following sudden death by accident in the 1970s and had experienced no known exposure to abnormally high levels of heavy metals during their lifetime \([6, 7]\). We could not obtain information on them regarding...
smoking. Absorption amount of Cd can be calculated from the data. The calculation method used is as follows. Let \( x \) and \( t \) be the accumulation amount of Cd in the whole body and age at sudden death. The accumulation amount of Cd in the whole body is expressed by using a differential equation as:

\[
\frac{dx}{dt} = -x \cdot \ln 2/\tau + \kappa \cdot f(t),
\]

where \( \tau \) is a BHT of Cd, \( f(t) \) is energy intake at age \( t \) [8], \( \kappa \) is a parameter, the first term of the right side members \(-x \cdot \ln 2/\tau \) means excretion amount of Cd per unit time, and the second term of the right side \( \kappa \cdot f(t) \) indicates absorption amount of Cd per unit time. As initial conditions, we can assume \( x = 0 \) when \( t = 0 \), then the unique solution to the differential equation (3) can be obtained. The unique solution will include unknown parameters \( \tau \) and \( \kappa \). When many data sets of \( x \) and \( t \) are available, the parameters can be estimated (\( \hat{\tau} \) and \( \hat{\kappa} \)) from the unique solution using the non-linear regression method [9]. The calculation method has been clearly described in articles [6, 7]. Assuming the age of an adult to be 50 years old, i.e. \( t = 50 \), the absorption amount of Cd per year \( \hat{\kappa} \cdot f(t) \) for adults can be obtained by using the method found in the articles [6, 7]. The value \( \hat{\kappa} \cdot f(t) \) is the mean for adults including both smokers and nonsmokers.

The amount of Cd in the whole body \( x \) is calculated as 1.5 \( x \) amount of Cd in the kidneys and liver [10]. Therefore \( x \) is obtained from the Cd concentrations and weights of the organs.

Results

Cd intake from food

The following values for the oral intake amount of Cd in Japan were employed: 48 \( \mu g \)/day for males in the 1970s [11], 44 \( \mu g \)/day for males and 37 \( \mu g \)/day for females in the 1980s [12], and 32 \( \mu g \)/day for females in the 1990s [13]. These values are shown in Table 1, showing that the oral intake amounts of Cd in Japan have decreased with time. A review article of studies on Cd exposure in Japan [14] reported the range of the oral intake amount of Cd for subjects in the 1970s in Japan to be \( 17-79 \mu g \)/day. We assume that the range of oral intake or fecal excretion amount of Cd to be the sum of the variations among individuals and within each individual, and that the two variations are independent of each other. The assumption that the variation in oral Cd intake amount is equivalent to the variation in Cd fecal excretion amount is also added. The geometric standard deviation (GSD) of the oral Cd intake amount for males in the 1980s was reported to be 1.86 [12], which corresponds to the range including the two variations. The mean coefficient of variation (CV) for the fecal excretion amount of Cd for each subject in one day in the 1970s, which indicates the variation within an individual, was calculated to be 41% [15]. We assume that GSD is constant. Under log-normal distribution, the relationship between GSD and CV:
\[ GSD = 1 + CV^2 \]
is obtained [16]. Then the variation among individuals for the oral Cd intake expressed by CV is obtained as:
\[
\sqrt{1.86 - 1} - 0.41 = 0.52
\]
(4)

Table 2 indicates the change in the mean intake amount of rice in Japan [17–19]. Table 2 shows decrease in the intake of rice in Japan.

**Cd absorption from smoking**

The number of adult residents in Japan by gender \( p_m \) and \( p_f \) [20] and the market share in Japan for cigarettes produced in Japan \( s_1 \) [21] are indicated in Table 3, and the smoking rates of adults in Japan by gender \( r_m \) and \( r_f \) [22], as well the number of cigarettes sold in Japan by country of production (press release from Japan Tobacco Incorporated in 1999) are shown in Table 4. In Table 3, numbers of imported cigarettes before 1980 were regarded as 0%. In Table 3, adult means 20 years old and over.

Unpublished information from Japan Tobacco Incorporated indicates that the proportions of tobacco leaves harvested in Japan used in cigarettes produced and sold in Japan, \( m_n \), were about 50% in 1998–1999 and 100% before the end of the 1980s. The article [3] reported the mean Cd amount in one cigarette by country of production to be \( z_r = 1.75 \mu g/\text{cigarette}, z_s = 1.07 \mu g/\text{cigarette}, \) and \( z_f = 1.08 \mu g/\text{cigarette}. \) Using equation (1), the mean amounts of

<table>
<thead>
<tr>
<th>Year</th>
<th>1960s</th>
<th>1970s</th>
<th>1980s</th>
<th>1990s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Intake</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiration [14]</td>
<td>0.3</td>
<td>0.3</td>
<td>3.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Smoking [3*]</td>
<td>2.3</td>
<td>0.4</td>
<td>3.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Absorption</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accumulation</td>
<td></td>
<td>6.8[6*]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food</td>
<td>5.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiration</td>
<td>(0.1)</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Smoking [3*]</td>
<td>0.9</td>
<td>0.2</td>
<td>1.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

[11–14]: citation No., [ * ]: calculation using the method described in the article
Cd in one cigarette sold in Japan by year were calculated from the above values as $y_{65} = 1.75 \, \mu g/cigarette$ in 1965, $y_{70} = 1.75 \, \mu g/cigarette$ in 1970, $y_{85} = 1.74 \, \mu g/cigarette$ in 1975, $y_{90} = 1.74 \, \mu g/cigarette$ in 1980, $y_{95} = 1.73 \, \mu g/cigarette$ in 1985, and $y_{98} = 1.33 \, \mu g/cigarette$ in 1998–1999. These calculated values, $y'$s, are shown in Table 4.

We calculated the mean amounts of Cd absorbed from smoking cigarettes in one day for each adult resident in Japan including both smokers and nonsmokers by gender and year using equation (2) to be $b_{65m} = 0.9(0.7–1.1) \, \mu g/day$ and $b_{65f} = 0.2(0.1–0.2) \, \mu g/day$ in 1965, $b_{70m} = 1.0(0.8–1.3) \, \mu g/day$ and $b_{70f} = 0.2(0.1–0.3) \, \mu g/day$ in 1970, $b_{85m} = 1.2(0.8–1.6) \, \mu g/day$ and $b_{85f} = 0.2(0.2–0.3) \, \mu g/day$ in 1975, $b_{90m} = 1.1(0.8–1.5) \, \mu g/day$ and $b_{90f} = 0.2(0.2–0.3) \, \mu g/day$ in 1990.

### Table 2. Amount of rice intake in Japan by year

<table>
<thead>
<tr>
<th>Year</th>
<th>Intake amount (g/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>346.6</td>
</tr>
<tr>
<td>1960</td>
<td>358.4</td>
</tr>
<tr>
<td>1965</td>
<td>349.8</td>
</tr>
<tr>
<td>1970</td>
<td>306.1</td>
</tr>
<tr>
<td>1975</td>
<td>248.3</td>
</tr>
<tr>
<td>1980</td>
<td>225.8</td>
</tr>
<tr>
<td>1985</td>
<td>216.1</td>
</tr>
<tr>
<td>1990</td>
<td>197.9</td>
</tr>
</tbody>
</table>

[17–19]: citation No.

### Table 3. Adult population in Japan by gender and year and market share in Japan for cigarettes produced in Japan

<table>
<thead>
<tr>
<th>Year</th>
<th>Adult population ($\times 1,000$)</th>
<th>Male</th>
<th>Female</th>
<th>Market share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>29,951</td>
<td>32,306</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>1970</td>
<td>33,656</td>
<td>36,177</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td>37,102</td>
<td>39,668</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>39,267</td>
<td>42,014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>41,558</td>
<td>44,478</td>
<td>97.6</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>48,153</td>
<td>51,467</td>
<td>76.5</td>
<td></td>
</tr>
</tbody>
</table>

[20, 21]: citation No.
-0.3) μg/day in 1980, $b_{750} = 1.1(0.7 - 1.4) μg/day$ and $b_{750} = 0.2(0.2 - 0.3) μg/day$ in 1985, and $b_{750} = 0.8(0.5 - 1.0) μg/day$ and $b_{750} = 0.2(0.1 - 0.2) μg/day$ in 1998 - 1999, where the figures in parentheses indicate the range calculated from $a = 25$ and $50 \%$. These $b$'s are shown in Tables 1 and 4. The $b$'s of the 1970s, 1980s, and 1990s in Table 1 were adopted from the values $b_{750}$, $b_{755}$, and $b_{785}$ in Table 4, respectively. The mean amounts of Cd inhaled from smoking ($b/a$) were also calculated, and the values can be seen in Table 1.

**Respiratory absorption of Cd**

The inhaled amount of Cd by respiration in the 1970s in Japan was 0.3 μg/day [14]. The absorption rate of Cd in the airways is $a = 37.5 \pm 12.5 \%$, and the absorption amount of Cd by respiration in the 1970s was to be as $0.1(0.1 - 0.2) μg/day$. The value is shown in Table 1.

**Calculation of Cd absorption from Cd accumulation in organs**

The mean amount of Cd absorbed in one day for male adults in the 1970s in Japan was calculated from data on 223 male subjects who underwent autopsy following sudden death by accident in the 1970s using equation (3) to be $K \cdot f(t) = 6.8 μg/day$, and the value is shown in Table 1. The calculated value is that for adult residents including both smokers and non-smokers, because we were not able to obtain information on them regarding smoking.

**Cadmium absorption rate in digestive organs**

The amount of Cd absorbed as calculated from Cd accumulation data was obtained in only

<table>
<thead>
<tr>
<th>Year (μg/cigarette)</th>
<th>Male</th>
<th>Female</th>
<th>Smoking rate</th>
<th>Number of cigarettes sold*</th>
<th>Total ($\times 10^6$)</th>
<th>Absorption amount of Cd from smoking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>1.75</td>
<td>0.823</td>
<td>0.157</td>
<td>172.1</td>
<td>0.4</td>
<td>172.5</td>
</tr>
<tr>
<td>1970</td>
<td>1.75</td>
<td>0.775</td>
<td>0.156</td>
<td>222.1</td>
<td>0.7</td>
<td>222.9</td>
</tr>
<tr>
<td>1975</td>
<td>1.74</td>
<td>0.762</td>
<td>0.151</td>
<td>289.8</td>
<td>3.3</td>
<td>293.1</td>
</tr>
<tr>
<td>1980</td>
<td>1.74</td>
<td>0.702</td>
<td>0.144</td>
<td>304.0</td>
<td>3.7</td>
<td>307.7</td>
</tr>
<tr>
<td>1985</td>
<td>1.73</td>
<td>0.646</td>
<td>0.137</td>
<td>303.2</td>
<td>7.5</td>
<td>310.7</td>
</tr>
<tr>
<td>1998</td>
<td>1.33</td>
<td>0.552</td>
<td>0.133</td>
<td>257.6</td>
<td>79.0</td>
<td>336.6</td>
</tr>
</tbody>
</table>

[22]: citation No., *: press release
the 1970s (Table 1). The absorbed amount of Cd calculated from Cd accumulation data in the 1970s is reflected by Cd absorption before the 1970s. From the 1970s column in Table 1 and the row on 1965 in Table 4, the amount of Cd absorbed from food before the 1970s is obtained as the difference between the absorbed Cd amounts using Cd accumulation data in the 1970s (Table 1), from smoking (Table 4) and respiration (Table 1), i.e.

$$6.8 \, \mu g/\text{day} - (0.1 + 0.9) \, \mu g/\text{day} = 5.8 \, \mu g/\text{day}, \quad (5)$$

with the value shown in Table 1. We substituted the amount of Cd absorbed by respiration in the 1970s for that obtained before the 1970s.

The Cd concentration in rice harvested in Japan is generally higher than that harvested in foreign countries [23–25]. It is inappropriate to ignore the change in amount of rice intake according to time when obtaining the amounts of Cd absorbed from food. The intake amount of rice in Japan in 1975 was 243.3 g/day and that in 1955–1965 was 346.6–358.4 g/day (Table 2), the difference between them being about 100 g/day. The mean Cd concentration of rice harvested in Japan in the 1970s was 0.07 μg/g [14]. The difference between the intake amount of Cd from rice in Japan in the 1950s–1960s and the 1970s was

$$0.07 \, \mu g/\text{g} \cdot 100 \, \text{g/day} = 7 \, \mu g/\text{day}. \quad (6)$$

Therefore the absorption rate of Cd in the digestive organs was calculated from equations (5) and (6) and Table 1 to be:

$$5.8 \, \mu g/\text{day}/(48 + 7) \, \mu g/\text{day} = 10.5\%, \quad (7)$$

assuming that most of the change in Cd intake from food is derived from the amount of rice eaten in Japan. The range of Cd absorption rate in the digestive organs was calculated from the CV of Cd oral intake (4) to be:

$$5.8 \, \mu g/\text{day}/|48 + 7| \cdot (1 \pm 0.52) \, \mu g/\text{day} | = 6.9 - 22.0\%. \quad (8)$$

### Discussion

The mean Cd amounts ingested from food in one day have decreased over the past few decades (Table 1). It has been reported that the concentration of Cd in rice harvested in Japan is generally higher than that in foreign countries [23–25]. The decrease of Cd intake amount in Japan is the result of a decrease in the amount of rice eaten in Japan [26] (Table 2). The concentration of Cd in tobacco leaves harvested in Japan is generally higher than that in leaves harvested in foreign countries [3, 5, 27]. Therefore the increase in the market share of cigarettes produced in foreign countries and sold in Japan (Table 4) and the increase in the proportion of tobacco leaves harvested in foreign countries used in cigarettes made and sold in Japan have resulted in a decrease in the mean amount of Cd inhaled and ab-
sorbed by persons smoking in Japan from 1980 (Tables 1 and 4).

Watanabe et al. published many articles on the amount of Cd intake from foodstuff [12, 13, 26, 28–30]. In these articles, identical subjects were used to obtain the amount of Cd intake in some articles and subjects including not only the above but also different subjects were used in others. Thus a precise meta-analysis could not be conducted to obtain the summarized value of the Cd intake amount from food using the values in the articles by Watanabe, and the article by Watanabe published in the middle of the 1980s [12] was used in order to obtain the amounts of Cd intake from food in the present study but the others were not. Differences between values for the amount of Cd intake from food in cited articles [12, 13, 26] and in the many articles by Watanabe which were not employed in the present study were not large. The value in the article by Suzuki et al. [11] is adequate when extrapolated using the values from the 1980s and 1990s considering the reasonable decrease in the values. Therefore it is reasonable to assume that the amount of Cd intake from food in the 1970s was 48 μg/day (Table 1) from the article by Suzuki [11] cited in the present study. A review article of studies on Cd in Japan [14] reported the range of oral intake amount on Cd exposure in the 1970s in Japan to be 17–79 μg/day, and its central value |(17 + 79)/2 μg/day| was 48 μg/day, which coincides with the value by Suzuki [11].

The concentrations of Cd in the atmosphere and drinking water in Cd unpolluted areas are not high [1, 2]. Therefore the sum of the amounts of Cd absorbed from food and smoking must be nearly equal to the amount of Cd absorbed as calculated from Cd accumulation data in organs and tissues in Cd unpolluted areas. However, the amount of Cd intake from food in the 1970s [11] contained Cd in drinking water. In the present study, the amount of Cd absorbed by respiration was not ignored. The sum of the absorbed amounts of Cd from food including drinking water and from smoking and respiration must coincide with the Cd absorption amount calculated from the Cd accumulation amount in organs and tissues.

The Cd absorption rate in digestive organs, 10.5(6.9–22.0)% in equations (7, 8), is somewhat higher than the values in some articles [1, 2], which showed 0.5–8% and 5–6%. This range in equation (8) is not narrow. An increase in the Cd absorption rate in digestive organs to 20% was reported in females whose intake of calcium and iron was insufficient [2]. The upper value of the Cd absorption rate in digestive organs in equation (8) is near the value for iron-insufficient females. In the present study, it is pointed out that the absorption rate of Cd in digestive organs is about 10%. This is an originality of the present study. Experimental methods were used in most studies to obtain the Cd absorption rate in digestive organs, while the value in the present study was obtained from information on Cd exposure in not only experimental but also epidemiologic studies.

In order to obtain the total Cd absorption amount calculated from Cd accumulation amount in organs, one hundred samples or more are necessary. We could not find such a study except for a set of Sugita’s studies obtaining biological half-time [6, 7]. Therefore the values in the 1960s and 1980s–1990s could not be obtained, and the value in the 1970s
was used in the present study.

In the present study we regarded the range of the intake amount of Cd from food to be large due to variation among individuals without taking into account variation within each individual. The variation of Cd accumulation amount in organs and tissues within an individual must be small when homeostasis in living things is taken into consideration. Therefore it is sufficient to make a comparison between the Cd absorption amounts from food and calculated from Cd accumulation amount in organs and tissues ignoring the variation within individual. Calculation for obtaining the range of the Cd absorption rate in digestive organs was conducted under many assumptions in the present study. The wide range of Cd absorption rate in the digestive organs in equation \((8)\) was derived from the variation of Cd intake from food, and the relationship between intake amount and absorption rate was ignored in the present study. Therefore the range should not be used for strict calculations.

The mean age of male subjects was 36 years old for obtaining the Cd intake amount from food in the 1970s \([11]\), while it was 50 years old for obtaining the Cd absorption amount calculated from Cd accumulation data in the present study. The Cd absorption amount calculated from Cd accumulation data is influenced by Cd exposure over a few decades before sudden death. Therefore the comparison between the Cd intake amount from food for male subjects 36 years of age and the Cd absorption amount for males 50 years of age calculated from Cd accumulation data is adequate in the present study.

The subjects examined to obtain the Cd absorption amounts from smoking and calculated from Cd accumulation data in the present study included both smokers and nonsmokers. Therefore the two Cd absorption amounts are comparable. We could not obtain information on smoking in regard to the subjects whose Cd accumulation data were used to calculate the Cd absorption amount. Therefore the Cd absorption amounts calculated from Cd accumulation data cannot be obtained according to smoking status. However, the Cd absorption amounts from smoking cigarettes can be obtained according to smoking status.

We ignored smoking by juveniles and variation of number of cigarettes smoked according to age and gender for obtaining the Cd absorption amount from smoking in the present study. The effect due to the above ignored factors is probably not large, because the Cd absorption amount from smoking is much smaller than that from food in Japan.

It is known that Cd concentrations of rice and tobacco leaves harvested in Japan are higher than those in foreign countries \([3, 5, 23-25, 27]\). Decrease in the Cd intake amount from food in Japan is shown \(\text{Table 1}\). However, the Cd intake amount from food in Japan is not small compared with that from food in foreign countries. The relationship between Cd concentrations in blood and urine and renal dysfunction for subjects in Cd-unpolluted area has been reported \([31]\). An epidemiologic study on the relationship between \((1)\) intake of rice and smoking and \((2)\) renal dysfunction in Cd-unpolluted areas is necessary.
Cadmium Absorption Rate in Digestive Organs

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日本におけるカドミウムの身体負荷研究より算出された消化管でのカドミウム吸収率の推定

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要 旨：消化管でのカドミウム(Cd)吸収率は0.5－8%であると述べられている。この値は実験的研究により得られた値である。本研究の目的は、Cd 経口摂取量および呼吸と喫煙による Cd 経気道吸収量と臓器内 Cd 蓄積量から算出された Cd 総吸収量を日本における実験的研究および疫学的研究を基に消化管での Cd 吸収率を求めることがある。1970年代日本人男性の Cd 経口摂取量は48 μg/day であり、1970年代に突然死で司法解剖された日本人男性223名の臓器内 Cd 蓄積量から Cd の総吸収量は6.8 μg/day として算出された。1970年代以前の Cd 曝露は1970年代の臓器内 Cd 蓄積量から算出された Cd 総吸収量に影響する。また60年代日本人男性の呼吸と喫煙による Cd 経気道吸収量は1.0 μg/day であったので、その両者の差は5.8 μg/day であり、この値は Cd 消化管吸収量である。また1955－1965年における日本国内の米消費量は1975年の1.4倍であった。当時の Cd 経口摂取量の変動の大部分は米消費量の変動によりと仮定すれば、消化管での Cd 吸収率は約10%であると推定された。この値は従来の文献の値よりやや高めである。

キーワード： 喫煙, 食事, カドミウム吸収量, 臓器内カドミウム蓄積量, 消化管カドミウム吸収率