Modulation of Maltose Preference by Selection from Dextrin, Maltose and Glucose Diets in Zinc-Deficient Rats

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Summary This study examined whether the chain length of glucose in the diet could affect the selection of foods by Zn-adequate and Zn-deficient rats. Dextrin, maltose and glucose were used as sources of carbohydrate in the diet and the selection patterns of the rats were analyzed for 28 d by a 3-choice selection. Diets provided as a set of three either Zn-adequate or Zn-deficient diets were rotated daily. The Zn-adequate control rats selected widely from the three diets throughout the 28 d. In contrast, rats fed a Zn-deficient diet selected exclusively and continuously the dextrin diet or dextrin and glucose diets from the three diets over the experimental periods. The average daily total food intakes of rats fed a Zn-deficient diet were very significantly decreased. The selections of dextrin, maltose and glucose diets in the 3-choice methods of the control rats were 5.7±1.6%, 5.8±2.0% and 2.7±0.9% g/d, respectively (p<0.05), and those of the Zn-deficient rats were 6.4±2.5%, 0.8±1.3% and 2.6±1.4% g/d, respectively (p<0.05). The ratios of the selected maltose-diet in the Zn-adequate control and the Zn-deficient rats were 40.8±13.8 and 9.0±15.6%, respectively (p<0.01) and those of the dextrin-diet were 40.3±11.4 and 63.0±22.3%, respectively (p<0.05). The decreased preference for the maltose-diet in the Zn-deficient rats may reflect the increased selection of the dextrin-diet.

Key Words zinc deficiency, maltose, dextrin, glucose

It is well known that zinc (Zn) deficiency causes a number of biochemical and physiological problems, such as alopecia, depigmentation of hair, dermatitis of paws, anorexia and growth retardation (1, 2). The daily food intake of Zn-deficient rats shows a characteristic cyclic pattern with a 3.5 d period (3, 4). The decreased food intake of rats fed a Zn-deficient diet follows growth retardation, while insulin action is reduced during Zn-deficiency (5) and force feeding of a Zn-deficient diet by a gastric tube cannot recover the weight of Zn-deficient rats (6, 7).

Zn-deficient rats show significantly increased preferences for the normally preferred sodium chloride and sucrose concentrations (8, 9) but do not reject a much higher concentration of hydrochloric acid and quinine sulfate solutions (9, 10). Parakeratosis and hyperkeratosis of the oral mucous membranes and tongue of Zn-deficient rats have been proposed (10–12). Zn deficiency induces structural disorder of the taste bud cells (13–15) and reduces carbonic anhydrase activity with correlated taste and lingual trigeminal nerve sensitivities (16). Distinct morphological changes in the pancreatic acinar cells (17) as well as the intestinal epithelium (17–21) of Zn-deficient rats have been reported. The pancreatic acinar cells of Zn-deficient rats show degenerative areas of cytoplasm containing fragments of the endoplasmic reticulum, free ribosomes, myeloid structures and other amorphous, intensely osmiophilic material (17). The gastrointestinal tract develops lesions that exhibit flattening of intestinal villi and mucosal ulcerations (17, 20, 21). Moreover, Zn-deficiency impairs growth, digestion, and absorption in the rat small intestine (22–24).

The structural changes induced by Zn-deficiency are associated with both decreased amylase activity in pancreatic juice (25) and maltase and sucrase activities in the intestine (21, 23, 26–29). Zn-deficiency may impair the absorption of water and electrolytes and can easily lead to diarrhea episodes (24).

Rains and Shay (30) investigated differences in macronutrient preferences in Zn-deficient and Zn-adequate rats for a 28-d study from complete macronutrient selection by simultaneously providing each animal with three different diets, each consisting mainly of either fat, protein or carbohydrate. When dextrin, maltose, sucrose, glucose and fructose were used as a source of carbohydrate in a diet for 28 d, the food intake of rats fed either a Zn-adequate or Zn-deficient diet was highest in the dextrin group (31). The food intakes of maltose and glucose groups were not different in rats fed a Zn-adequate diet, but the food intake of the maltose group was higher than that of the glucose group in rats fed a Zn-deficient diet (31).

In this paper, we investigated the change of preference for carbohydrate in rats under the structural and functional disorders induced by Zn-deficiency. With a 3-choice method for selection from dextrin, maltose and...
glucose diets, Zn-adequate control rats selected the three diets uniformly, while the Zn-deficient rats continued to select the dextrin diet or dextrin and glucose diets. Selection of the maltose-diet was extremely low in the Zn-deficient rats. The daily total food intake of the Zn-deficient rats showed a wave and fitted a Cosine curve with a 3.8±0.3 d period.

MATERIALS AND METHODS

Animals. Male albino rats (Wistar/ST, 4 wk) were purchased from Japan SLC Co. Ltd. (Hamamatsu, Japan) and housed in individual screen-bottomed cages in a room maintained at 23±1°C with 50% humidity, under controlled lighting conditions (lights on from 07:00 to 19:00). The animals were fed a commercial stock diet of Oriental MF (Oriental Yeast Co., Ltd., Tokyo, Japan) and given tap water with free access for 3 d before the experiment to allow acclimatization to their new environment. The rats were given the experimental diet for 4 wk, and sacrificed between 09:00 and 11:00 under anesthetics with diethyl ether. Food intake and body weight were determined by weighing daily between 09:00 and 11:00. All procedures were performed in accordance with the Kobe Gakuen University Guidelines for the Care and Use of Laboratory Animals.

The three diets were placed at a fixed position in cage and rotated daily in order. All rats were given the experimental diet and deionized water with free access.

Diets. The compositions of the Zn-deficient dextrin, maltose, and glucose diets, and the Zn-adequate control dextrin, maltose, and glucose diets are shown in Table 1. The composition of the Zn-deficient diet was the same as that of the Zn-adequate control diets with the exception that ZnCO₃ was deleted from the salt mixture. The contents of Zn in the Zn-deficient dextrin, maltose, and glucose diets from the mean values of three separate experiments were 0.95, 0.90, and 0.75 mg/kg, respectively, while the contents of Zn in the Zn-adequate control dextrin, maltose, and glucose diets were 32, 31, and 32 mg/kg, respectively. The dietary energies in the dextrin, maltose and glucose diets were 16.5, 15.9 and 14.8 kJ/g, respectively. The diet was in powder form and contained in a 9-cm-diameter glass jar covered with a stainless steel lid containing nine 1.2-cm-diameter holes.

Chemicals. All chemicals used were of analytical grade and were purchased from Nacalai Tesque (Kyoto, Japan) unless otherwise stated. Animal feed was obtained from Oriental Yeast Co., Ltd. Dextrin, maltose and glucose were from Nacalai Tesque. Maltose and glucose used for dietary ingredients were D-form.

Zn content. A 1-g portion of each test diet was heated for 48–72 h in a muffle oven at 450°C. After the sample cooled, 2 mL of 1 M HCl was added, and the digestates were heated and diluted with double-distilled deionized water. The serum was diluted 1:4 with 0.83 M HCl and incubated for 30 min at about 4°C. After brief centrifugation (600 x g for 10 min), the supernatant was removed and used for analysis. The stock Zn and sample solutions were analyzed by atomic absorption spectroscopy with a Hitachi Z-5300 Polarized Zeeman Atomic Absorption Spectrophotometer (Hitachi Ltd., Tokyo, Japan) at 213.8 nm.

Evaluation of food intake and body weight changes. Daily food intake and body weight change data from Zn-deficient rats were analyzed by the Cosinor method (4, 33, 34). Food intake (F) and body weight change (ΔB) on day t were determined using the following equation:

\[ F(\text{or } \Delta B) = M + A \cos(2\pi t/\tau + \phi) \]

Where M, A, \( \tau \) and \( \phi \) represent the mesor (the rhythm-adjusted mean), amplitude (maximum and minimum values of the adjusted mean), period (length of one complete cycle) and acrophase (phase of maximum value), respectively. The experimental data were fitted to the above equation by the nonlinear least-squares method (35), and the four parameters, M, A, \( \tau \) and \( \phi \), were calculated using subroutine analysis (36).

As the data from Zn-adequate rats were not fitted to the above equation, comparisons among groups were evaluated between mean variation of daily food intake

Table 1. Compositions of the diets (g/kg).

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Control</th>
<th>Zn-deficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg albumin</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Carbohydrate¹</td>
<td>632.486</td>
<td>632.486</td>
</tr>
<tr>
<td>Soybean oil</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Vitamin mixture²</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Salt mixture (+Zn)</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Salt mixture (−Zn)</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Cellulose powder</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Choline hydrogen tartrate</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>tert-Butylhydroquinone</td>
<td>0.014</td>
<td>0.014</td>
</tr>
</tbody>
</table>

¹ Carbohydrates used were dextrin, maltose, and glucose.
² AIN-93G vitamin mixture (32) was purchased from Oriental Yeast Co., Ltd (Tokyo, Japan).
³ AIN-93G mineral mixture (32) was purchased from Oriental Yeast Co., Ltd.
⁴ Minerals (−Zn) (g/kg diet): ZnCO₃ was omitted from AIN-93G mineral mixture (32).

Fig. 1. Weight gain over time in rats fed a Zn-adequate diet (○) or a Zn-deficient diet (●). Each rat was simultaneously and continuously provided with three diets: dextrin, maltose and glucose diets. Values are mean±SD, n=10.
Fig. 2. Daily intake of Zn-adequate dextrin, maltose and glucose diets over time. Rats 1 to 10 were simultaneously and continuously provided with three Zn-adequate diets: dextrin (□), maltose (▲) and glucose (○) diets.

Fig. 3. Daily intake of Zn-deficient dextrin, maltose and glucose diets over time. Rats 11 to 20 were simultaneously and continuously provided with three Zn-deficient diets: dextrin (□), maltose (▲) and glucose (○) diets.
and body weight change. The variation was calculated for each rat with the standard deviation of the estimate of the day-to-day variation in food intake and body weight change for 28 d, and the group means are presented.

Statistical analysis. Values for food intake, weight gain and weight change are expressed as mean±SD. One-way analysis of variance (ANOVA) was used to compare the groups. When a significant difference (p<0.05) was found between groups, the statistical significance of the difference between values was assessed by Student’s t-test. When a significant difference (p<0.05) was found among carbohydrates selected in Zn-adequate and Zn-deficient rats, the statistical significance of the difference between/among values was assessed using Duncan’s multiple comparison test and considered significant at p<0.05.

RESULTS

Weight gain of rats fed a Zn-adequate diet and a Zn-deficient diet

The initial average body weights of the Zn-adequate and Zn-deficient groups were 144±5, and 137±5 g, respectively. The Zn-deficient rats showed typical symptoms of Zn deficiency such as alopecia, dermatitis of the paws, and anorexia with growth retardation. Figure 1 shows the average weight gain with the standard deviation. The weight gain of the Zn-adequate control rats, which continuously selected diets from the separate dextrin, maltose and glucose diets, increased linearly under the experimental conditions, while that from the Zn-deficient rats was retarded. After 28 d, the weight gains of rats fed Zn-adequate and Zn-deficient diets from the 3-choice method were 102±13 and 20±19 g, respectively (p<0.01).

The mean Zn concentrations of the serum at 28 d in the control and Zn-deficient rats from the 3-choice method were 2.6±0.3 and 0.9±0.4 μg/mL, respectively (p<0.01).

Food intake of either Zn-adequate rats or Zn-deficient rats selecting from separate maltose- and glucose-containing diets

The levels of daily food intake selected from a three-choice method of dextrin-, maltose- and glucose-containing diets in either Zn-adequate rats or Zn-deficient rats are shown in Figs. 2 and 3. Many of the rats fed a Zn-adequate diet showed selection of diets with no specific preference over a long time (Fig. 2). In contrast, many rats fed a Zn-deficient diet consistently rejected the maltose diet or maltose and glucose diets from the set of three diets throughout the experimental period (Fig. 3). Although the three diet jars of the dextrin, maltose and glucose diets were replaced daily and rotatively, all rats fed the Zn-adequate and Zn-deficient diets continuously maintained their preferences by selection from the three diets. Therefore, both rat groups could discriminate between the dextrin, maltose and glucose diets.

The feeding patterns and the preference of carbohydrate in the three-choice method showed a characteristic difference between the Zn-adequate and Zn-deficient rats. All of the rats fed a Zn-adequate diet selected the maltose diet during the 28 d (Fig. 2), while only one rat (#11) fed a Zn-deficient diet preferred the maltose diet compared to the dextrin and glucose diets (Fig. 3). Rats 13, 16 and 17, given a Zn-deficient diet, preferred dextrin diet exclusively to maltose and glucose diets throughout the experimental period (Fig. 3).

Average daily intake of diets by selection from the dextrin, maltose, and glucose diets, and the total diet intake were calculated from Figs. 2 and 3 and are shown in Fig. 4. The selection of the maltose diet and the total food intake (dextrin+maltose+glucose diets) in rats fed a Zn-deficient diet was significantly lower than in rats fed a Zn-adequate control diet. Rats fed a Zn-adequate diet showed no general preference among dextrin and maltose and glucose diets, while rats fed Zn-deficient diet selected the maltose diet least among the three diets (Fig. 4). The level of selection of the dextrin diet was not different between the control and Zn-deficient rats. But the total food intake in the Zn-deficient rats was significantly decreased. Therefore, the ratio of the selected dextrin diet to the total food intake in rats fed a Zn-deficient diet was 63.0±22.3% and was significantly higher than 40.3±11.4% in the Zn-adequate control rats (p<0.05).

Food intake and body-weight change cycles of rats fed a Zn-deficient diet

The day-to-day variation in the total food intake of rats fed a Zn-deficient diet from a three choice method was 3.77±1.10 g/d and was significantly larger than that of rats fed a Zn-adequate diet 1.57±0.54 g/d (p<0.01). This high value of the variation results in a Cosinor curve of the daily food intake of the Zn-deficient rats. The four parameters of the mean value of the cycles of food intake of the Zn-deficient rats were calculated and illustrated (Table 2). The body-weight changes in
the previous 24-h period of each rat were also fitted to a Cosinor curve (not shown), and the values of the four parameters were as follows: $M$, 0.6±0.7 g/d; $A$, 4.2±1.1 g/d; $\tau$, 3.6±0.3 d; $\phi$, −0.4±2.1 radian. The period of the body-weight change cycle was the same as that of the food intake cycle. The body-weight changes follow the food intake of rats fed a Zn-deficient diet, as shown in the previous papers (4, 33, 34). Neither the total food intake nor body-weight change, in the Zn-adequate rats was correlated to a Cosinor curve.

**DISCUSSION**

In this paper we examined whether rats have a preference for carbohydrates with different chain lengths of D-glucose, under conditions of Zn-adequacy and Zn-deficiency. Using a three-choice method by selection from dextrin, maltose and glucose diets, we found a characteristic pattern in the diet selection and a differing preference for carbohydrates between the Zn-adequate and the Zn-deficient rats.

The Zn-adequate control rats selected uniformly from the three diets, but the Zn-deficient rats selected exclusively the same one or two diets from the three diets over the experimental periods (Figs. 2 and 3). Changes of gustatory sensation in Zn-deficient rats have been reported (8–10). Zn-deficient rats showed significantly increased preferences for the normally preferred sodium chloride and sucrose concentrations (8, 9). Moreover, while Zn-adequate control animals rejected hydrochloric acid and quinine sulfate solution, the Zn-deficient rats did not indicate rejection until tested with a much higher concentration of the sour and bitter solutions (9, 10). Zn-deficient rats also showed some changes of a gustatory nature with parakeratosis and hyperkeratosis of the oral mucous membranes and tongue (10–15). The decreased taste acuity by Zn-deficiency may reduce the range of diet selection. Although the rats fed a Zn-deficient diet could discriminate among dextrin, maltose and glucose in the diets, some of them continued to select one or two diets for a long time; rat 11 continuously selected the maltose diet, and rats 13, 16 and 17 proceeded with a selection of the dextrin diet.

The maltose diet selection from dextrin, maltose and glucose diets showed a remarkable difference between the Zn-adequate and Zn-deficient rats. The Zn-adequate control rats preferred the maltose diet as well as the dextrin diet to the glucose diet, while the Zn-deficient rats refused the maltose diet. Zn-deficient animals have diminished maltase activity in the small intestine (21) and decreased pancreatic juice volume (25). Harper and Spivey (37) found an inverse relationship between the osmotic pressure exerted by a dietary carbohydrate and food intake. However, in the previous single diet method (31), we reported that the food intake of the maltose diet was higher than that of the glucose diet in Zn-deficient rats. These results suggest that the diminished selection of the maltose diet from among dextrin, maltose and glucose diets in the Zn-deficient rats may not be the result of structural and functional damage to the digestive organs or elevated osmotic pressure by the maltose diet intake, but may be due to a dislike for maltose over dextrin and glucose. Given the regressive taste acuity described in the above paragraph, many Zn-deficient rats may reject a maltose diet.

The ratio of the selected dextrin diet to the total food intake in rats fed a Zn-deficient diet was significantly higher than that in rats fed a Zn-adequate control diet. It is well established that dextrin is easily digested to glucose with amylase and maltase. The decreased amylase in pancreatic juice (25) and maltase activity in the intestine (23, 26) may not prevent the preference for dextrin diet in rats fed a Zn-deficient diet.

When dextrin, maltose and glucose are used as sucrose of carbohydrates in the single diet method (31), the daily food intake of the Zn-deficient rats shows a characteristic cyclic variation that fits well to a Cosinor curve. In this paper, the same cyclic feeding behavior was also found for the sum of food intake of the Zn-deficient rats from a three-choice method. The activities of the digestive enzymes of maltase and sucrase show circadian variations, being high at night and low in the daytime in rats fed a Zn-adequate diet ad libitum (38).
Saito et al. (38–40) proposed that the disaccharidase rhythms are not a direct consequence of food intake, but that anticipation of food intake acts as a trigger for initiation of the disaccharidase rhythm. In the previous paper (31) we found that food intake of the maltose diet or the sucrose diet in rats fed a Zn-deficient diet shows a cyclic variation not seen in rats fed a Zn-adequate diet. Therefore, the digestive enzymes of maltase and sucrase in the small intestine could not affect the cyclical food intake of the Zn-deficient rats in the three-choice method and a selection from three diets did not obstruct the appearance of the cyclical food intake.

When the daily food intake data from the Zn-deficient rats was fitted to a Cosinor curve, the correlation values \( r^2 \) of their intake cycles of dextrin, maltose and glucose diets were 0.631 ± 0.117, 0.612 ± 0.136 and 0.564 ± 0.169, respectively, in the single diet method (31). The correlation value \( r^2 \) of their food intake cycle from the three-choice method was weakened to 0.377 ± 0.146. The period of food intake cycle of rats fed a Zn-deficient diet using the three choice method was 3.8 ± 0.3 d and was not different from those of 3.5 ± 0.3, 3.8 ± 0.2 and 3.7 ± 0.2 d for dextrin, maltose and glucose diets, respectively, in the single diet method (31). When the Zn-deficient rats pick their food by selection among three diets, the average food intake showed a fixed pattern of 3.5–3.8 d cycles, but the behavior of food selection might slip slightly out the fixed pattern of the food intake cycle.

The Zn-deficient rats continued to select the same one or two diets from among the three diets throughout 28 d. These results suggest that the favorite carbohydrate of the Zn-deficient rats does not change between the peaks or troughs of their food intake cycle. The choice of food from the three diets sustained the cyclical food intake of the Zn-deficient rats. These results show that there is no direct correlation between the selection of carbohydrates and the cause of cyclical food intake in the Zn-deficient rats. The characteristic food intake cycle and a mechanism of distaste for the maltose diet of the Zn-deficient rats must be resolved by further studies including taste receptors.

References


7) MacDonald RS. 2000. The role of zinc in growth and cell proliferation. J Nutr 130: 1508S–1508S.


