Ingestion of guar-gum hydrolysate partially restores calcium absorption in the large intestine lowered by suppression of gastric acid secretion in rats

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We examined the effects of feeding guar-gum hydrolysate (GGH), a highly fermentable form of dietary fibre with low viscosity, on Ca absorption in the small and large intestines in rats under conditions in which gastric acid secretion was suppressed by a proton pump inhibitor, omeprazole. We also examined the role of the caecum in influencing these effects. The study was designed in a 2 × 2 × 2 factorial arrangement with two diet (GGH-containing (50 g/kg diet) and GGH-free diets) groups, two injection (omeprazole and vehicle) groups and two operation (sham and caecectomy) groups. Apparent Ca absorption was lower in rats administered omeprazole (30 mg/kg body weight per d) for 8 d than in rats administered the vehicle. Ingestion of GGH led to partial restoration of Ca absorption decreased by omeprazole treatment. However, this increment in Ca absorption was not sufficient to meet requirements because the dietary Ca level (3 g/kg diet) was the minimum requirement for the intact rats. The small increment in Ca absorption caused by the GGH diet was completely abolished by caecectomy. Soluble Ca pools in the caecal and colonic contents were increased by feeding GGH, and the soluble Ca concentrations were much higher than the Kt values of the Ca active transport system in the large intestine or the serum Ca concentration. These findings suggest that Ca solubilization is not a limiting factor for Ca absorption in the large intestine. Apparent Mg absorption was clearly lower in caecectomized rats than in sham-operated rats, and higher in the GGH-fed groups than in the groups fed on the GGH-free diet, even in the case of caecectomized rats. We conclude that Ca absorption lowered by inhibition of gastric acid secretion is partially restored in rats fed with GGH, but the increment is not sufficient to meet requirements.

**Caution: Guar gum: Gastric acid**

Major dietary sources of Ca are insoluble salts, and solubilization of these Ca salts by gastric acid is an essential step for absorption of Ca via the intestine. Therefore, impairment of gastric acid secretion may be associated with malabsorption of Ca. It is reported that the absorption of insoluble Ca salts is decreased in patients with achlorhydria (Recker, 1985), and in a rat model of achlorhydria (Mahoney et al., 1975). Previously, we demonstrated that intestinal Ca absorption lowered by partial nephrectomy was fully restored as a result of feeding guar-gum hydrolysate (GGH; Hara et al., 1996), a highly fermentable dietary fibre material with low viscosity (Takahashi et al., 1994). The increase in Ca absorption was dependent on the large intestine (Hara et al., 1996).

Enhancement of caecal fermentation is known to increase caecal absorption of Ca (Demigné et al., 1989; Younes et al., 1996). Karbach & Feldmeier (1993) showed that the large intestine has a large capacity for Ca absorption. Furthermore, it was previously demonstrated that feeding of fructo-oligosaccharides, which are very poorly absorbed, enhanced Ca absorption via the large intestine upon administration of an insoluble Ca source into the caecum (Ohta et al., 1997). Ingestion of other fermentable oligosaccharides is also known to increase Ca absorption (Ammann et al., 1988; Brommage et al., 1993; Chonan & Watanuki, 1995). Recently, Ohta et al. (1998) showed that Ca absorption lowered by total gastric resection recovered completely on feeding fructo-oligosaccharides. However, the mechanism and role of caecal fermentation in enhancement of Ca absorption on feeding oligosaccharides have not been clarified. Moreover, the effects of soluble dietary fibre on Ca absorption under conditions of impairment of gastric acid secretion are not known.

The purpose of the present study was to examine apparent

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**Abbreviations:** CCX, caecectomized; GGH, guar-gum hydrolysate.

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Ca absorption and Ca dynamics in the small and large intestines after feeding GGH to rats treated with a proton pump inhibitor, omeprazole (Elander et al. 1986), with or without caecectomy. The caecum substantially contributes to large-intestinal fermentation in rats. We also examined apparent Mg absorption under the same conditions for comparison with Ca absorption.

**Experimental methods**

**Animals and diets**

Fifty-eight male Sprague-Dawley rats (Japan SLC, Hamamatsu, Japan), weighing about 100 g, were given free access to deionized water and the semi-purified stock diet shown in Table 1 for an acclimatization period of 5 d, and were divided into two groups, one of thirty-four rats and one of twenty-four rats. Rats of the first group were subjected to laparotomy (sham-operated group) and rats of the second group were subjected to caecectomy (CCX group) and rats of the other two sub-groups were administered its vehicle (PEG 400–NaHCO₃ (10 mg/kg diet); GuarFiber, Meiji Seika Kaisha Ltd, Tokyo, Japan) and the other two sub-groups were administered omeprazole (30 mg/kg body weight). Two rats from the CCX group died with operative damage. Two of the sub-groups of each operation group were divided into four sub-groups of eight rats (CCX) and six rats (sham) using a randomized block design based on body weight. Two rats from the CCX group died with operative damage. Two of the sub-groups of each operation group were subcutaneously administered omeprazole (30 mg/kg body weight, kindly provided by Astra Japan, Osaka, Japan), and the other two sub-groups were administered its vehicle (PEG 400–NaHCO₃ (10 mM); 1 : 1, v/v). Omeprazole or the vehicle was injected once daily at 16:00–17:00 hours. From the next day after starting administration of omeprazole or the vehicle, the diet fed to four sub-groups (omeprazole-treated sham and CCX groups) was changed to the test diet containing GGH (50 mg/kg diet; GuarFiber, Meiji Seika Kaisha, Ltd, Tokyo, Japan) and the diet fed to the other four sub-groups was changed to the GGH-free test diet. The animals were fed on the test diets for a period of 7 d. In the last 6 d period, coprophagy was prevented by means of a wire-mesh anal cup as described before (Ohta et al. 1996). Faeces were collected during the last 3 d to evaluate Ca and Mg excretion and apparent absorption of Ca and Mg. All faeces excreted in the 3 d period were collected from the anticoprophagy anal cups, and were freeze-dried.

Rats used in the experiment were housed individually in stainless-steel cages with mesh bottoms. The cages were placed in a room with controlled temperature (22–24°C), relative humidity (40–60%) and lighting (lights on: 08:00–20:00 hours).

At the end of the experiment, the rats were killed under pentobarbital anaesthesia. The distal half of the small intestine (ileum), caecum and colon were removed immediately without loss of their contents, and their contents were completely removed for further analysis.

GGH is a partial hydrolysate of guar gum, prepared by digestion with β-1,4-mannanase (EC 3.2.1.25), having an average molecular mass of 15,000, and this material was added to the test diet, as a source of dietary fibre, to give a concentration of 50 g/kg. Rats were given free access to the test diet and deionized water during the test period. Body weight and food intake were measured every day.

This study was approved by the Hokkaido University Animal Committee, and animals were maintained in accordance with the Hokkaido University guidelines for the care and use of laboratory animals.

**Analytical methods**

Freeze-dried faeces were milled. Powdered faecal material (about 70 mg) was wet-ashed with 5 ml of a mixture of 10 m-HNO₃ and 2.3 m-HClO₄ under temperature-controlled conditions, 150°C for the first 30 min then 200°C, taking care to prevent the samples drying out during digestion. The caecal and colonic contents diluted with nine volumes of deionized water, and the ileal contents washed out of the removed segment with 10 ml deionized water, were homogenized by means of a Teflon homogenizer. Amounts of total Ca in the contents were measured after the sub-sampled homogenate had been wet-ashed in the same way as the faeces. Soluble Ca was assayed in the supernatant fraction obtained on centrifugation (30 000 × g for 20 min) of sub-sampled homogenate. Ca and Mg concentrations in the ashed solutions were measured by atomic absorption spectrophotometry (AA-6400F; Shimadzu, Kyoto, Japan) after adequate dilution with water.

**Calculations and statistical analysis**

Apparent absorption of Ca or Mg was calculated as follows: apparent Ca (Mg) absorption (%) = 100 × (total Ca (Mg) intake – faecal Ca (Mg) excretion)/total Ca (Mg) intake.

### Table 1. Composition (g/kg diet) of stock and test diets

<table>
<thead>
<tr>
<th>Test diets*</th>
<th></th>
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</thead>
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</tr>
<tr>
<td>Casein†</td>
<td>250</td>
</tr>
<tr>
<td>Maize oil‡</td>
<td>50</td>
</tr>
<tr>
<td>Mineral mixture (Ca free)§</td>
<td>27</td>
</tr>
<tr>
<td>Ca carbonate</td>
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<tr>
<td>Vitamin mixture</td>
<td>1.0</td>
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<tr>
<td>Granulated vitamin E¶</td>
<td>1.0</td>
</tr>
<tr>
<td>Choline bitartrate</td>
<td>4.0</td>
</tr>
<tr>
<td>Sucrose</td>
<td>to make 1 kg</td>
</tr>
</tbody>
</table>

* The composition of the stock diet was the same as that of the test diet except for the Ca concentration (45 g/kg diet). Guar-gum hydrolysate (GuarFiber, Meiji Seika Kaisha Ltd, Tokyo, Japan; 50 g/kg diet) was added to the test diets with and without guar gum hydrolysate. Both fibre sources were added to the test diets at the expense of the whole diet.

† ALACID; New Zealand Dairy Board, Wellington, New Zealand.

‡ Crystalline cellulose (Avicel PH102, Asahi Chemical Industry Co. Ltd, Tokyo, Japan; 50 g/kg diet), 50 g/kg diet, was added to the test diets with and without guar gum hydrolysate. Both fibre sources were added to the test diets at the expense of the whole diet.

§ The mineral mixture was prepared as established by the AIN-76 Workshop held in 1989 (Reeves, 1989), without Ca. It provided (mg/kg diet): P 2997, K 3746, Mg 375, Fe 100, Zn 34.7, Cu 6.00, Na 4279, Cl 6542, Se 1.05, Mo 1.00, Cr 0.50, B 0.50, V 0.25, Sn 2.00, As 1.00, Si 200, Ni 1.00, F 27.2, Co 0.20. The Ca concentration in the stock diet was 4.5 g/kg diet and that in the test diet was 3.0 g/kg diet.

¶ The vitamin mixture was prepared in accordance with the AIN-76 mixture (American Institute of Nutrition, 1977) except that menadione and L-ascorbic acid were added at 5.81 μmol/kg diet (American Institute of Nutrition, 1980) and 284 μmol/kg diet (Harper, 1959) respectively.

‖ The vitamin mixture was prepared in accordance with the AIN-76 mixture (American Institute of Nutrition, 1977) except that menadione and L-ascorbic acid were added at 5.81 μmol/kg diet (American Institute of Nutrition, 1980) and 284 μmol/kg diet (Harper, 1959) respectively.

* The vitamin mixture was prepared in accordance with the AIN-76 mixture (American Institute of Nutrition, 1977) except that menadione and L-ascorbic acid were added at 5.81 μmol/kg diet (American Institute of Nutrition, 1980) and 284 μmol/kg diet (Harper, 1959) respectively.
Weights of caecal and colonic contents were evaluated as the differences between weights of the caecum and colon with their contents and their washed wall weights.

The results were analysed by three-way ANOVA (caecectomy, omeprazole and GGH). Duncan’s multiple range test was used to determine whether mean values were significantly different (\(P < 0.05\)). These statistical analyses were done by the general linear models procedure of the Statistical Analysis Systems program (version 6.07 SAS Institute Inc., Cary, NC, USA).

Results

Table 2 shows the changes in body weight and food intake. Final body weight was not changed by caecectomy, omeprazole treatment or feeding GGH, however, body-weight gain was influenced by omeprazole treatment as indicated by the results of ANOVA.

As shown in Fig. 1(a), apparent Ca absorption in the omeprazole-treated groups was lower than that in the non-treated groups of sham and CCX rats. In the omeprazole-treated groups, the absorption rate in the rats fed on the GGH-containing diet was significantly higher than that in the sham rats fed on the GGH-free diet, but not in the CCX rats. The levels of Ca absorption in CCX rats were also lower than those in sham rats, except for the group treated with omeprazole and fed on the GGH-free diet.

Mg absorption rates (Fig. 1(b)) were significantly higher in the GGH-fed groups than in the groups fed on the GGH-free diet. In the sham rats, the absorption rate in the omeprazole-treated groups was lower than that in the non-omeprazole-treated sham groups, but not in the CCX rats. Changes in faecal dry weight during the 3d period were very similar to those observed for the colonic contents.

As shown in Table 4, the total Ca pools in the caecal and colonic contents of sham rats were much larger in the omeprazole-treated groups than in the vehicle-treated groups. In contrast, the soluble Ca pool in the sham rats was not changed by omeprazole treatment. In both the omeprazole- and vehicle-treated groups, the caecal soluble Ca pools were larger in the GGH-fed rats than in the rats fed on the GGH-free diet. In the sham rats, changes in colonic total and soluble Ca pools were similar to those in the caecal Ca pools. In CCX rats, the total colonic Ca pools were larger than in the sham rats, especially in the omeprazole-treated groups. As indicated by the results of ANOVA, the colonic total Ca and soluble Ca pools were affected by caecectomy, omeprazole treatment and GGH feeding. The ileal soluble Ca pool was smaller in the omeprazole-treated groups than in the sham groups.

As shown in Table 5, the pH of the caecal contents in the omeprazole- and vehicle-treated sham groups was lower in rats fed on the GGH-containing diet than in rats fed on the GGH-free diet, and, among the GGH-fed rats, the pH value in the omeprazole-treated group was higher than that in the vehicle-treated group. Changes in the pH of the colonic contents were similar to those observed for the caecal

<table>
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<tr>
<th>Treatment</th>
<th>Initial body weight Mean</th>
<th>SE</th>
<th>Final body weight Mean</th>
<th>SE</th>
<th>Body-weight gain Mean</th>
<th>SE</th>
<th>Food intake Mean</th>
<th>SE</th>
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<tbody>
<tr>
<td>Sham operation</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>- OM, - GGH</td>
<td>154</td>
<td>4.1</td>
<td>171</td>
<td>4.9</td>
<td>16.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.1</td>
<td>13.1</td>
<td>0.97</td>
</tr>
<tr>
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<td>152</td>
<td>3.1</td>
<td>174</td>
<td>4.9</td>
<td>21.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.4</td>
<td>13.5</td>
<td>0.97</td>
</tr>
<tr>
<td>+OM, - GGH</td>
<td>153</td>
<td>3.0</td>
<td>168</td>
<td>3.8</td>
<td>15.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.0</td>
<td>12.4</td>
<td>0.40</td>
</tr>
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<td>3.3</td>
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<td>3.7</td>
<td>13.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.9</td>
<td>12.8</td>
<td>0.55</td>
</tr>
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<td>Caecectomy</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>- OM, - GGH</td>
<td>155</td>
<td>2.0</td>
<td>177</td>
<td>3.0</td>
<td>22.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.4</td>
<td>13.2</td>
<td>0.43</td>
</tr>
<tr>
<td>- OM, +GGH</td>
<td>154</td>
<td>2.4</td>
<td>172</td>
<td>2.4</td>
<td>18.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.6</td>
<td>13.0</td>
<td>0.43</td>
</tr>
<tr>
<td>+OM, - GGH</td>
<td>154</td>
<td>1.9</td>
<td>170</td>
<td>4.0</td>
<td>15.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.6</td>
<td>12.0</td>
<td>0.49</td>
</tr>
<tr>
<td>+OM, +GGH</td>
<td>156</td>
<td>2.3</td>
<td>169</td>
<td>3.0</td>
<td>12.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.1</td>
<td>12.2</td>
<td>0.45</td>
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</table>

Statistical significance (ANOVA) of effect of:

- Caecectomy: NS
- Omeprazole: NS
- GGH: NS

<sup>a,b</sup> Mean values within a column not sharing a common superscript letter were significantly different, \(P < 0.05\) (Duncan’s multiple range test).

* For details of diets and procedures, see Table 1 and pp. 316–317.
ever, the increment obtained through GGH feeding was absorption were partially restored on feeding GGH, how-
a result of omeprazole treatment. The lowered levels of Ca
effects. Apparent Ca absorption was decreased by 25% as
fermentation in the large intestine in influencing these
We studied the effects of feeding GGH on intestinal Ca
changes in (a) apparent calcium absorption and (b) apparent
contents in sham rats. In CCX rats, the pH of the colonic
contents was lower in the GGH group than in the group fed
on the GGH-free diet. Omeprazole treatment did not influ-
ence the pH of the colonic contents in CCX rats.

Discussion
We studied the effects of feeding GGH on intestinal Ca absorption in rats with gastric acid secretion suppressed by
omeprazole treatment, and examined the involvement of fermentation in the large intestine in influencing these
effects. Apparent Ca absorption was decreased by 25% as a result of omeprazole treatment. The lowered levels of Ca
absorption were partially restored on feeding GGH, how-
ever, the increment obtained through GGH feeding was
completely abolished in CCX rats. These results show that
the large intestine is responsible for the small increment in
Ca absorption lowered by suppression of gastric acid secre-
tion. It is unlikely that this dietary fibre affects small-
intestinal Ca absorption because GGH is a dietary fibre
with very low viscosity. The small increase in apparent Ca
absorption observed may be associated with the caecal
fermentation of GGH. Caecal fermentation products,
short-chain fatty acids, are known to enhance intestinal Ca
absorption (Lutz & Scharrer, 1991; Trinidad et al. 1996)
Caecectomy suppressed fermentation and degradation of
GGH. The observation that faecal excretion increased as a
result of feeding GGH in CCX rats, but not in sham rats
(Table 3) indicates the suppression of fermentation of this
fibre. The amount of GGH ingested by each rat was
approximately 2 g in a 3 d period (calculated from Table
2), and the increase in faecal dry weight in this 3 d period
was about 1 g as a result of feeding GGH. These results
show that half of the ingested GGH was excreted by the
CCX rats. This estimation reveals that a considerable
amount of ingested GGH was fermented in the colon of the
CCX rats, and our finding that the pH of the colonic
contents was lowered in CCX rats (Table 5) supports this
conclusion. However, as described earlier, caecectomy
abolished the enhancement of Ca absorption completely.
Furthermore, GGH feeding substantially increased the
amount of soluble Ca in the colon in CCX and vehicle-
treated rats; however, the level of Ca absorption did not
change.

The colon has an extensive capacity for Ca absorption
(Ammann et al. 1986; Pitcher & Buffenstein, 1994). It is
reported that the Ca concentration at half VMAX (Kt)
for active Ca transport are 0.94 mmol/l (Karbach & Rummel,
1987) and 1.6 mmol/l (Favus et al. 1981) in the ascending
and descending colon respectively. We did not measure the
amount of water in the colonic contents. It is usually
approximately 50% (Ohta et al. 1995). From the values
obtained for the soluble Ca pool, shown in Table 4, the
concentration is estimated as 15–35 mmol/l, which is much
higher than Kt values for colonic Ca absorption described
earlier, and also much higher than the serum Ca concentra-
tion (about 2.5 mmol/l; H. Hara, unpublished results). These
results indicate that soluble Ca concentration in the colon is
sufficiently high for transcellular and paracellular absorp-
tion. Ohta et al. (1995) showed that colonic absorption of Ca
increased as a result of feeding highly fermentable oligo-
saccharides to intact rats. Furthermore, the level of dietary
Ca in the present study was 3.0 g/kg diet, which is the
minimum requirement for intact rats as shown in the
previous study (Hara et al. 1996). In rats with lowered Ca
absorption (groups other than the sham group not treated
with omeprazole), the Ca levels are insufficient to meet
requirements and these rats need to absorb more Ca. Our
findings suggest that solubilization of Ca is not a rate-
limiting step for Ca absorption in the colon. Other factors,
for example absorptive activity in the large intestine, may
play a crucial role in Ca absorption.

As in previous observations concerning partially nephrec-
tomized rats, Ca absorption was decreased to an extent
comparable with that in omeprazole-treated rats. The low-
ered levels of Ca absorption resulting from nephrectomy
recovered to the level observed in intact rats on feeding a
diet containing the same level of GGH as in the diet used in
the present study. In contrast, Ca absorption in the omepr-
azole-treated rats was increased significantly but insuffi-
ciently. Lowered pH of the caecal contents (Table 5) and
no increase in faecal excretion (Table 3) in GGH-fed rats
compared with rats fed on the GGH-free diet show that
ingested GGH was fermented almost completely in the large
intestine in the sham rats. The concentration of soluble Ca in
the caecal contents was 6–10 mmol/l, as calculated from the
data in Table 4, and the amount of water in the caecal
contents was approximately 70 % (the results of a separate
experiment). The solubilization of Ca in the caecal contents
may not be rate limiting for caecal Ca absorption as in the

**Table 3.** Changes in weight of the caecal and colonic contents (g wet weight/rat), and excreted
faeces (g DM/3 d) of rats after administration of omeprazole (OM), feeding of guar-gum
hydrolysate (GGH) diet and caecectomy or sham operation*  
(Mean values with their standard errors for six rats in the sham groups and eight rats in the
caecectomized groups)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Caecal content Mean (g)</th>
<th>SE</th>
<th>Colonic content Mean (g)</th>
<th>SE</th>
<th>Faeces Mean (g)</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sham operation</td>
<td>−OM, −GGH</td>
<td>1.36 a</td>
<td>0.11</td>
<td>0.512 ab</td>
<td>0.042</td>
<td>2.79 bc</td>
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<td></td>
<td>−OM, +GGH</td>
<td>3.75  a</td>
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<td>0.743 cd</td>
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<td>0.412 A</td>
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<td>2.37 c</td>
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<td>0.28</td>
<td>0.683  cd</td>
<td>0.136</td>
<td>2.86 bc</td>
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<td>Caecectomy</td>
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<td>0.869 c</td>
<td>0.136</td>
<td>3.10 b</td>
<td>0.12</td>
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<td>1.622 a</td>
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<td>0.850 c</td>
<td>0.071</td>
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<td>1.317 b</td>
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Statistical significance (ANOVA) of effect of:

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<th>Caecectomy</th>
<th>OM</th>
<th>GGH</th>
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<tr>
<td></td>
<td>NS</td>
<td>NS</td>
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<tr>
<td>P &lt; 0.001</td>
<td>P &lt; 0.001</td>
<td>P &lt; 0.001</td>
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</tbody>
</table>

* For details of diets and procedures, see Table 1 and pp. 316–317.

**Table 4.** Total Ca pool and soluble Ca pool (mg/rat) in the caecal colonic contents of rats after administration of omeprazole (OM), feeding of guar-gum hydrolysate (GGH) diet and caecectomy or sham operation*  
(Mean values with their standard errors for six rats in the sham groups and eight rats in the caecectomized groups)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ileal contents</th>
<th>Caecal contents</th>
<th>Colonic contents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Ca Mean (mg)</td>
<td>SE</td>
<td>Soluble Ca Mean (mg)</td>
</tr>
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<td>Sham operation</td>
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<td>0.065</td>
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<td>−OM, −GGH</td>
<td>0.658 a</td>
<td>0.140</td>
</tr>
<tr>
<td></td>
<td>−OM, +GGH</td>
<td>0.589 ab</td>
<td>0.096</td>
</tr>
<tr>
<td></td>
<td>+OM, −GGH</td>
<td>0.323 bc</td>
<td>0.072</td>
</tr>
<tr>
<td></td>
<td>+OM, +GGH</td>
<td>0.248 c</td>
<td>0.053</td>
</tr>
</tbody>
</table>

Statistical significance (ANOVA) of effect of:

<table>
<thead>
<tr>
<th>Caecectomy</th>
<th>OM</th>
<th>GGH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>P = 0.002</td>
<td>P &lt; 0.001</td>
<td>P &lt; 0.001</td>
</tr>
</tbody>
</table>

* For details of diets and procedures, see Table 1 and pp. 316–317.
Table 5. Changes in the pH of the caecal and colonic contents of rats after administration of omeprazole (OM, 30 mg/kg per d), feeding of guar-gum hydrolysate (GGH) diet and caecectomy or sham operation*  
(Mean values with their standard errors for six rats in the sham groups and eight rats in the caecectomized groups)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH of the caecal contents</th>
<th>pH of the colonic contents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SE</td>
</tr>
<tr>
<td>Sham operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- OM, - GGH</td>
<td>7.17^a</td>
<td>0.18</td>
</tr>
<tr>
<td>- OM, + GGH</td>
<td>5.64^c</td>
<td>0.09</td>
</tr>
<tr>
<td>+ OM, - GGH</td>
<td>6.83^a</td>
<td>0.04</td>
</tr>
<tr>
<td>+ OM, + GGH</td>
<td>6.12^a</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Caecectomy |               |     |               |     |
| - OM, - GGH | –           |     | 7.05^a     | 0.03 |
| - OM, + GGH | –           |     | 6.25^c     | 0.09 |
| + OM, - GGH | –           |     | 6.98^a     | 0.04 |
| + OM, + GGH | –           |     | 6.27^c     | 0.10 |

Statistical significance (ANOVA) of effect of:

<table>
<thead>
<tr>
<th>Caecectomy</th>
<th>OM</th>
<th>GGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>–</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>OM</td>
<td>P&lt;0.001</td>
<td>NS</td>
</tr>
<tr>
<td>GGH</td>
<td>P&lt;0.001</td>
<td>P&lt;0.001</td>
</tr>
</tbody>
</table>

^a,b,c,d Mean values within a column not sharing a common superscript letter were significantly different, P<0.05 (Duncan’s multiple range test).

*For details of diets and procedures, see Table 1 and pp. 316–317.

References


case of colonic absorption described earlier. Feeding of GGH lowered the pH and increased the soluble Ca pool in the caecal contents; however, these changes were not associated with sufficient recovery of Ca absorption lowered by omeprazole treatment even under conditions of mild Ca deficiency. Karbach & Feldmeier (1993) showed that the caecum has the highest capacity for Ca absorption. In mole rats (Cryptomys hottentotus), it has been shown that the highest capacity for active uptake of Ca is in the caecum (Pitcher & Buffenstein, 1994). Possibly omeprazole itself or some other factor in omeprazole-treated rats, prevents the increase in Ca absorption in the large intestine.

The soluble Ca pool in the ileal contents clearly decreased, while the total Ca pool in the caecal contents substantially increased as a result of omeprazole treatment (Table 4). These results demonstrate that suppression of Ca solubilization and a decrease in Ca absorption in the small intestine occur in omeprazole-treated rats. The dose of omeprazole used in the present study was rather high, and gastric acid secretion is suppressed for 24 h by this dose of omeprazole (Segawa et al. 1987; Seensalu et al. 1990). The results concerning ileal levels of soluble and total Ca show that a considerable amount of Ca salt was solubilized in the small intestine even in rats treated with omeprazole. Factors other than gastric acid may contribute to the solubilization of Ca salts in the proximal intestine.

Mg absorption was decreased as a result of caecectomy in both the omeprazole-treated and non-treated rats. This finding indicates that the caecum and the colon substantially contribute to Mg absorption, and agrees with reports indicating that the predominant site of Mg absorption is the large intestine (Chutkow, 1964, 1966). Also, in the CCX rats, GGH feeding slightly but significantly enhanced Mg absorption, which reveals that colonic Mg absorption is increased in rats fed on GGH. These observations show that the large intestine contributes to Mg absorption more than to Ca absorption, especially in the case of the colon. This result agrees with our previous report (Ohta et al. 1995). Omeprazole treatment did not influence Mg absorption because we used a soluble Mg salt (MgSO4) in the test diets.

Although the present study showed that ingestion of a low-viscosity highly fermentable dietary fibre increased Ca absorption, this did not fully restore the insoluble Ca absorption impaired by suppression of gastric acid secretion. This increment of Ca absorption may be beneficial for patients with achlorhydria or patients with gastric ulcer using a proton pump inhibitor because Ca absorption from insoluble dietary sources may decrease greatly in these patients as shown in our experiment using a rat model. The present study also showed that the large intestine is responsible for Mg absorption, which indicates an increase in the incidence of Mg deficiency in patients with a resected large intestine.
Calcium absorption in rats is stimulated by dietary lactulose and other resistant sugars. *Journal of Nutrition** 123, 2186–2194.


