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

Hiroshi Hara[1]*, Takuya Suzuki[1], Takanori Kasai[1], Yoritaka Aoyama[1] and Atsutane Ohta[2]

[1]*Department of Bioscience and Chemistry, Faculty of Agriculture, Hokkaido University, Sapporo 060-8589, Japan*
[2]*Bioscience Laboratories, Meiji Seika Kaisha, Ltd, Sakado 350-02, Japan*

(Received 29 May 1998 – Revised 14 October 1998 – Accepted 30 November 1998)

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 $2\times2\times2$ 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 (3·0 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 *K*t 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.

Calium: 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

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

* **Corresponding author:** Dr Hiroshi Hara, fax +81 11 716 0879, email hara@chem.agr.hokudai.ac.jp

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 caecectomy (CCX group) and rats of the second group were subjected to laparotomy (sham-operated group) under anaesthesia (pentobarbital sodium, 40 mg/kg body weight; Abbott, North Chicago, IL, USA). After a recovery period (4 d) on the stock diet, the sham and CCX groups were each 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–$NaHCO_3$ (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 g/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°), 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.

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

	Test diets*
Casein†	250
Maize oil‡	50
Mineral mixture (Ca free)§	27
Ca carbonate	7·5
Vitamin mixture‖	10
Granulated vitamin E¶	1·0
Choline bitartrate	4·0
Sucrose	to make 1 kg

* The composition of the stock diet was the same as that of the test diet except for the Ca concentration (4·5 g/kg diet). Guar-gum hydrolysate (GuarFiber, Meiji Seika Kaisha Ltd, Tokyo, Japan; 50 g/kg diet) was added to the test diet. Crystalline cellulose (Avicel PH102, Asahi Chemical Industry Co. 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.

‡ Retinyl palmitate (7·66 μmol/kg diet) and ergocalciferol (0·0504 μmol/kg diet) were added to the maize oil. Ergocalciferol was excluded from the test diet used in experiments 2–4.

§ 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, I 0·32, Mn 10·0, 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 20·0, Ni 1·00, F 2·72, 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.

¶ Vitamin E granules (Juvela, Eisai Co., Tokyo, Japan) supplied 423 μmol all-rac-α-tocopheryl acetate/kg of diet.

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-HNO_3 and 2·3 M-$HClO_4$ under temperature-controlled conditions, 150° for the first 30 min then 200°, 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.

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 ($P < 0{\cdot}05$). 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, except for the omeprazole-treated sham rats. The levels of Mg absorption in all CCX groups were much lower than those in all sham groups. Omeprazole treatment did not influence Mg absorption.

The wet weights of the caecal contents in sham rats and the colonic contents in CCX rats were greater in the GGH-fed groups than in the groups fed on the GGH-free diet (Table 3). In the sham rats, the wet weight of the colonic contents was significantly higher in the GGH-fed group than in the group fed on the GGH-free diet in the rats administered omeprazole, but not in the rats administered the vehicle. Changes in faecal dry weight during the 3 d 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 2. Initial and final body weights (g), and changes in body weight and food intake (g/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)

	Initial body weight		Final body weight		Body-weight gain		Food intake	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sham operation								
−OM, −GGH	154	4·1	171	4·9	16·6[ab]	3·1	13·1	0·97
−OM, +GGH	152	3·1	174	4·9	21·8[a]	2·4	13·5	0·97
+OM, −GGH	153	3·0	168	3·8	15·5[ab]	2·0	12·4	0·40
+OM, +GGH	154	3·3	167	3·7	13·1[b]	2·9	12·8	0·55
Caecectomy								
−OM, −GGH	155	2·0	177	3·0	22·3[a]	1·4	13·2	0·43
−OM, +GGH	154	2·4	172	2·4	18·3[ab]	1·6	13·0	0·43
+OM, −GGH	154	1·9	170	4·0	15·2[ab]	2·6	12·0	0·49
+OM, +GGH	156	2·3	169	3·0	12·1[b]	3·1	12·2	0·45
Statistical significance (ANOVA) of effect of:								
Caecectomy	NS		NS		NS		NS	
OM	NS		NS		$P = 0{\cdot}002$		NS	
GGH	NS		NS		NS		NS	

[a,b] Mean values within a column not sharing a common superscript letter were significantly different, $P < 0{\cdot}05$ (Duncan's multiple range test).

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

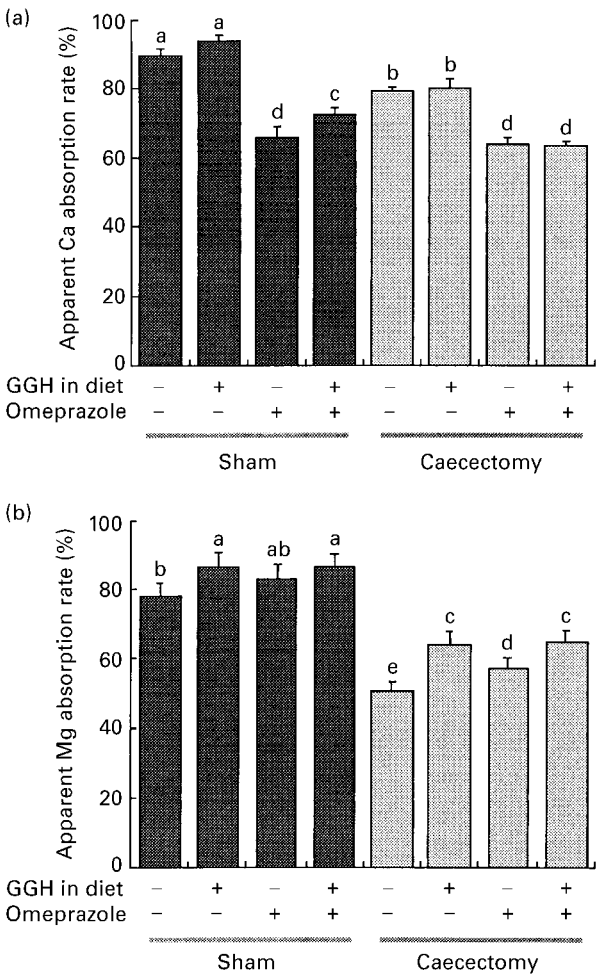

Fig. 1. Changes in (a) apparent calcium absorption and (b) apparent magnesium absorption of sham-operated or caecectomized rats fed on a diet containing guar-gum hydrolysate (GGH) with or without omeprazole treatment (30 mg/kg body weight per d). All values are means with their standard errors for six rats in the sham groups and eight rats in the caecectomized groups. *P* values estimated by three-way ANOVA were: panel (a), $< 0{\cdot}001$ for GGH, $< 0{\cdot}001$ for omeprazole treatment and 0·010 for caecectomy; and panel (b), $< 0{\cdot}001$ for GGH, not significant for omeprazole treatment and $< 0{\cdot}001$ for caecectomy. Mean values not sharing a common letter were significantly different between diet groups ($P < 0{\cdot}05$) according to Duncan's multiple range test.

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 influence 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, however, 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 secretion. 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 V_{MAX} (*K*t) 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 *K*t values for colonic Ca absorption described earlier, and also much higher than the serum Ca concentration (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 absorption. Ohta *et al*. (1995) showed that colonic absorption of Ca increased as a result of feeding highly fermentable oligosaccharides 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 nephrectomized rats, Ca absorption was decreased to an extent comparable with that in omeprazole-treated rats. The lowered levels of Ca absorption resulting from nephrectomy

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)

	Caecal content		Colonic content		Faeces	
Treatment	Mean	SE	Mean	SE	Mean	SE
Sham operation						
−OM, −GGH	1·36[b]	0·11	0·512[de]	0·042	2·79[bc]	0·45
−OM, +GGH	3·75[a]	0·35	0·743[cd]	0·132	2·83[bc]	0·20
+OM, −GGH	2·00[b]	0·19	0·412[e]	0·069	2·37[c]	0·10
+OM, +GGH	3·04[a]	0·28	0·683[cd]	0·136	2·86[bc]	0·11
Caecectomy						
−OM, −GGH	–		0·869[c]	0·136	3·10[b]	0·12
−OM, +GGH	–		1·622[a]	0·074	4·14[a]	0·21
+OM, −GGH	–		0·850[c]	0·071	2·91[bc]	0·12
+OM, +GGH	–		1·317[b]	0·082	4·11[a]	0·19
Statistical significance (ANOVA) of effect of:						
Caecectomy	–		$P<0·001$		$P<0·001$	
OM	NS		NS		NS	
GGH	$P<0·001$		$P<0·001$		$P<0·001$	

[a,b,c,d,e] 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.

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 omeprazole-treated rats was increased significantly but insufficiently. 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 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)

	Ileal contents				Caecal contents				Colonic contents			
	Total Ca		Soluble Ca		Total Ca		Soluble Ca		Total Ca		Soluble Ca	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sham operation												
−OM, −GGH	0·574[ab]	0·111	0·363[ab]	0·086	2·14[b]	0·514	0·280[b]	0·043	0·990[de]	0·173	0·226[c]	0·034
−OM, +GGH	0·507[abc]	0·112	0·376[a]	0·080	3·06[b]	0·877	1·030[a]	0·296	0·781[e]	0·225	0·309[c]	0·087
+OM, −GGH	0·499[abc]	0·117	0·182[bc]	0·024	10·80[a]	2·28	0·343[b]	0·033	2·790[abc]	0·706	0·201[c]	0·015
+OM, +GGH	0·336[bc]	0·065	0·187[bc]	0·054	8·78[a]	0·660	0·771[a]	0·195	2·880[ab]	0·604	0·369[bc]	0·039
Caecectomy												
−OM, −GGH	0·658[a]	0·140	0·338[abc]	0·060	–		–		2·53[bc]	0·350	0·533[b]	0·065
−OM, +GGH	0·589[ab]	0·096	0·380[a]	0·052	–		–		2·28[bc]	0·296	1·120[a]	0·121
+OM, −GGH	0·323[bc]	0·072	0·193[c]	0·032	–		–		3·77[a]	0·280	0·249[c]	0·051
+OM, +GGH	0·248[c]	0·053	0·176[c]	0·041	–		–		1·77[cd]	0·261	0·372[bc]	0·061
Statistical significance (ANOVA) of effect of:												
Caecectomy	NS		NS		–		–		$P=0·034$		$P<0·001$	
OM	$P=0·002$		$P<0·001$		$P<0·001$		NS		$P<0·001$		$P<0·001$	
GGH	NS		NS		NS		$P=0·004$		$P=0·010$		$P<0·001$	

[a,b,c,d,e] 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 procesures, 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)

	pH of the caecal contents		pH of the colonic contents	
Treatment	Mean	SE	Mean	SE
Sham operation				
−OM, −GGH	7·17[a]	0·18	7·04[a]	0·10
−OM, +GGH	5·64[c]	0·09	6·05[d]	0·13
+OM, −GGH	6·83[a]	0·04	6·97[a]	0·04
+OM, +GGH	6·12[b]	0·13	6·50[b]	0·06
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:				
Caecectomy	–		NS	
OM	NS		NS	
GGH	$P < 0·001$		$P < 0·001$	

[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.

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 ($MgSO_4$) 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.

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