Post-prandial changes in pH and electrolyte concentration, in the upper jejunum after truncal vagotomy and drainage in man¹

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SUMMARY The changes in pH and concentration of electrolytes in the jejunal lumen after a hyper-tonic fluid meal have been studied after truncal vagotomy and drainage, with and without diarrhoea. The results show that, in these respects, there are no specific changes in the jejunal content associated with post-vagotomy diarrhoea, but that these measurements are markedly affected by the completeness of vagotomy, as judged by the insulin test.

Little is known about the composition of the upper jejunal content after ingestion of a meal after truncal vagotomy and drainage (Lewicki *et al.*, 1973). With operations of this kind there may be undesirable sequelae related to and perhaps caused by abnormalities in gastric emptying (Colmer *et al.*, 1973), and consequently interference with the normal admixture of food, and biliary and pancreatic secretions (Wastell and Ellis, 1966). As a result, the jejunal lumen may receive chyme of abnormal composition and this could be of some importance in the aetiology of post-vagotomy diarrhoea.

This study reports the changes in pH and electrolyte concentration in the lumen of the upper small bowel in patients after truncal vagotomy and drainage, with and without diarrhoea, compared with a group of subjects who have not had any gastric operation. The relationship of the composition of the small bowel content to post-vagotomy diarrhoea was investigated particularly.

Methods

SUBJECTS

Twenty-one patients were studied after truncal vagotomy and drainage. After operation, seven individuals had diarrhoea, defined as the passage of three or more liquid stools per day. All the patients

were studied at least 12 weeks after operation and informed consent was obtained in every case (Table 1). An insulin test of gastric secretion was performed at an interval of at least three months after operation. Interpretation of the results was according to Hollander's original criteria (1948), with the addition of a second hour's collection period. The response was judged to be either negative, early positive (within 60 minutes after insulin), or late positive (60-120 minutes after insulin). Eleven of the patients were insulin negative and therefore presumed to have a complete vagotomy and 10 were insulin positive (Table 1), three exhibiting an early and seven a late response.

Thirteen subjects formed a contrast group, in that they had not been subjected to any gastric operation. Six were healthy and seven had an uncomplicated duodenal ulcer.

The upper jejunum was intubated by passing a long narrow polyvinyl tube of internal diameter 2.5 mm

	Insulin - ve		Insulin + ve	
	Diarrhoea free	Diarrhoea	Diarrhoea free	Diarrhoea
Pyloroplasty	3	3	3	3
Posterior gastrojejunostomy	5	0	3	1
Total	8	3	6	4
				Contrast
Normal				6
Duodenal ulcer				7
Total				13

Table 1 Subjects studied after truncal vagotomy

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through the mouth and allowing it to advance until its tip lay just beyond the ligament of Treitz (Blankenhorn *et al.*, 1955), the position being checked by radiographic screening. In the case of patients with a gastroenterostomy, care was taken to ensure that the tube was directed into the efferent loop of the stoma. After a 12 hour fast, each subject drank a 300 ml fluid test meal (Table 2), consisting of cow's milk containing 26 g sucrose (Temple *et al.*, 1975).

Volume	300 ml
Osmolality	590 mOsm/kg
pH	6.67
Cl ⁻	32 mEq/l
Na ⁺	23 mEq/l
K ⁺	31 mEq/l

Table 2 Analysis of the meal

Samples were obtained in 30 minute aliquots by continuous syphonage and collected under oil in flasks chilled by surrounding ice. The pH of each was measured immediately on a pH meter and subsequently each sample was centrifuged. Fractions of the supernatant were then used to estimate the concentration of sodium and potassium on an auto-analyser and chloride on a chloride meter.

Statistical analyses were carried out using Student's *t* test.

Results are expressed as the mean value $\pm$ SE.

Results

There was no statistical difference in the mean pH and electrolyte concentrations in the jejunal aspirates between healthy subjects and the patients with an uncomplicated duodenal ulcer. Therefore, all these results have been pooled to form a contrast group for comparison with those from the postoperative patients (Table 3). In Figs 1, 2, 3, and 4 the shaded area represents mean $\pm$ SE for this contrast group.

JEJUNAL PH

In general, the jejunal pH of post-vagotomy subjects was related to the results of the insulin test. In insulin negative patients, the jejunal content was more alkaline throughout the test than either insulin positive or contrast subjects (Fig. 1), these differences being significant until the last 30 minutes of the test (Table 4). Insulin positive patients had a mean initial pH of 6.15 ± 0.09 , but during the remainder of the test the luminal content became more acid, the final pH value being 4.75 ± 0.39 .

Seven of the post-vagotomy patients had diarrhoea. Those patients with an apparently incomplete vagotomy had a more acid jejunal content than those with a complete vagotomy, and there was no particular relationship between jejunal pH and post-vagotomy diarrhoea.

Fig. 1 pH values (post-vagotomy) of upper jejunal aspirates. Means $\pm$ SE are shown. — Complete vagotomy. - - - Incomplete vagotomy. ■ Contrast.

Time after ingestion of meal (min)	pH			[Na ⁺]mEq/l			[K ⁺]mEq/l			[Cl ⁻]mEq/l		
	Normal	Duodenal ulcer	Contrast	Normal	Duodenal ulcer	Contrast	Normal	Duodenal ulcer	Contrast	Normal	Duodenal ulcer	Contrast
30	5.91 $\pm$ 0.15	5.99 $\pm$ 0.1	5.96 $\pm$ 0.08	72 $\pm$ 5	70 $\pm$ 4	71 $\pm$ 3	17.02 $\pm$ 1.2	17.25 $\pm$ 0.87	17.15 $\pm$ 0.69	62 $\pm$ 3	66 $\pm$ 2	65 $\pm$ 2
60	5.26 $\pm$ 0.54	5.12 $\pm$ 0.37	5.19 $\pm$ 0.34	65 $\pm$ 6	72 $\pm$ 4	69 $\pm$ 3	16.62 $\pm$ 1.0	14.79 $\pm$ 0.59	13.63 $\pm$ 0.6	76 $\pm$ 5	87 $\pm$ 3	82 $\pm$ 3
90	4.68 $\pm$ 0.41	4.73 $\pm$ 0.36	4.70 $\pm$ 0.27	82 $\pm$ 8	88 $\pm$ 6	86 $\pm$ 5	13.63 $\pm$ 0.59	12.11 $\pm$ 0.85	12.81 $\pm$ 0.56	99 $\pm$ 6	108 $\pm$ 5	104 $\pm$ 4
120	4.76 $\pm$ 0.5	4.94 $\pm$ 0.65	4.86 $\pm$ 0.4	102 $\pm$ 12	103 $\pm$ 8	103 $\pm$ 6	11.13 $\pm$ 0.82	8.9 $\pm$ 0.89	10.21 $\pm$ 0.7	112 $\pm$ 6	111 $\pm$ 5	112 $\pm$ 3
150	5.64 $\pm$ 0.4	4.91 $\pm$ 0.63	5.22 $\pm$ 0.4	112 $\pm$ 11	108 $\pm$ 7	110 $\pm$ 6	9.8 $\pm$ 0.58	9.56 $\pm$ 0.95	9.29 $\pm$ 0.51	113 $\pm$ 4	116 $\pm$ 6	115 $\pm$ 4

Table 3 Jejunal pH and electrolyte concentrations: contrast group (subjects who have not had any gastric operation)

Values represent mean $\pm$ SEM. Contrast group = mean of normal and duodenal ulcer groups.

Time after ingestion of meal (min)	Complete vagotomy to contrast	Complete vagotomy to incomplete vagotomy
30	2 P < 0.001	2 P < 0.02
60	2 P < 0.001	2 P < 0.05
90	2 P < 0.001	2 P < 0.01
120	2 P < 0.02	2 P < 0.01
150	NS	NS

Table 4 pH of jejunal aspirates: significance of differences between (1) complete vagotomy and contrast groups, (2) complete vagotomy and incomplete vagotomy groups

JEJUNAL ELECTROLYTE CONCENTRATIONS

Sodium concentration

The jejunal concentration of sodium in post-vagotomy subjects showed an entirely different pattern from that in the contrast group. There was a rapidly increasing sodium concentration during the first 60 minutes of the test (Fig. 2). Indeed, at 60 minutes the value in the complete vagotomy group had risen to 109 mEq/l and at 90 minutes to 120 mEq/l. These results were both significantly greater than the concentrations measured at similar times in either the incomplete vagotomy subjects of 89 ± 4 mEq/l (2 P < 0.01) and 93 ± 3 mEq/l (2 P < 0.005), or the contrast subjects 69 ± 3 mEq/l (2 P < 0.001) and 86 ± 5 mEq/l (2 P < 0.001). At 120 and 150 minutes, sodium concentration in the incomplete vagotomy group was similar to that found in the contrast group. Patients with a complete vagotomy, however, continued to maintain a higher sodium concentration than either the incomplete vagotomy

or the contrast subjects throughout the test period.

There was no relationship between post-vagotomy diarrhoea and jejunal sodium concentration. The subjects who had a complete vagotomy continued to have a higher sodium concentration than those with an incomplete vagotomy.

Potassium concentration

All the post-vagotomy patients also showed a steady fall in potassium concentration (Fig. 3), but the value at 60 minutes in both the insulin negative and the insulin positive patients was significantly lower than that in the contrast group (2 P < 0.001 in each case), irrespective of the presence or absence of post-vagotomy diarrhoea. After 60 minutes the potassium concentration of the patients with an incomplete vagotomy became similar to that of the contrast group. Patients with a complete vagotomy continued to have a lower concentration of potassium in their jejunal content than either the incomplete vagotomy patients or contrast subjects,

Fig. 2 Concentration of sodium (post-vagotomy) in upper jejunal aspirates. Means $\pm$ SE are shown. Key as in Fig. 1

Fig. 3 Concentration of potassium (post-vagotomy) in upper jejunal aspirates. Means $\pm$ SE are shown. Key as in Fig. 1.

but this difference was only significant at 90 minutes ($2 P < 0.01$ and $2 P < 0.001$ respectively).

Chloride concentration

The chloride concentration of the post-vagotomy subjects showed clearly that there was no difference between those who are insulin negative and positive (Fig. 4). Also, both post-vagotomy groups had a similar chloride concentration to the contrast group except during the first 30 minutes after ingestion of the meal. At that time, the mean chloride concentration of the complete vagotomy group ($53 \pm \text{mEq/l}$) and the incomplete group ($55 \pm \text{mEq/l}$) were significantly lower than the contrast group ($2 P < 0.02$ and $2 P < 0.001$ in each case).

Fig. 4 Concentration of chloride in upper jejunal aspirates. Means $\pm$ SE are shown. Key as in Fig. 1.

Discussion

The findings of this study clearly show that, after truncal vagotomy and drainage, the pH and concentrations of sodium and potassium in the upper small bowel content are related chiefly to the completeness of vagal section as judged by Hollander's criteria for interpretation of the insulin test (Hollander, 1948). Post-vagotomy diarrhoea has no particular association at all with these findings.

The similar pH values in the upper small bowel in

normal subjects and patients with an active duodenal ulcer is in accord with other reported studies (Rhodes *et al.*, 1966; Rhodes and Prestwich, 1966; Worning *et al.*, 1967). A decreasing jejunal pH during the first 80 minutes after ingestion of a meal was found in dogs by Mann and Bollman (1930) and this has been our experience in the present study. Using a similar intubation technique, Fields and Duthie (1965) and Worning and Müllertz (1966) did not find this marked fall in pH. *In vivo* direct recording pH electrodes are, of course, theoretically more accurate than aspirated samples for measurement of this type, but Benn and Cooke (1971) compared these two methods of measuring the pH in the upper jejunum and found no significant differences between the results.

Early in the investigation, it became apparent that the insulin status of the patients had a significant bearing upon the pH values recorded in the upper jejunum. Our finding that the jejunal pH of the negative insulin group was more alkaline than the incomplete group, or the contrast individuals, complements the pattern of pH values measured in the subjects with hypochlorhydria compared with normal subjects as noted by Worning and Müllertz in 1966. When the pH values of the patients with post-vagotomy diarrhoea and known insulin status are studied, it is apparent that the presence or absence of diarrhoea itself has no particular association with the pH values or for that matter with the electrolyte composition of the upper small bowel content.

The initial phase of relatively constant sodium concentration seen in the contrast subjects for one hour after ingestion of the meal has not been reported before. This is the time during which the pH in the upper jejunum is falling rapidly. It is well known that in human gastric juice the observed sodium concentration appears to reach its highest value at the same time as the acidity is approaching neutrality and, therefore, there is an inverse relationship between the concentration of sodium and pH in gastric juice (Makhlouf *et al.*, 1966). It seems that there is likewise an inverse relationship between the pH value and sodium concentration in the jejunal lumen, as the patients with complete vagotomy—and therefore less acid in the jejunum—had a significantly greater sodium concentration than the contrast individuals. Those patients with an incomplete vagotomy adopt an intermediate position, having a significantly greater sodium concentration and more acid pH only during the 30–60 minute period after the meal, and thereafter equating with the contrast subjects. Once again, those with an incomplete vagotomy had a lower sodium concentration and more acid jejunal pH than those who were insulin negative. The presence or absence of post-

vagotomy diarrhoea itself apparently does not effect these measurements in the jejunal lumen. Neither did diarrhoea have any bearing upon the concentration of potassium or chloride. The gradual fall in potassium concentration seen in all the subjects is only to be expected because, in the jejunum, this ion is governed by the concentration gradients across the jejunal mucosa (Turnberg, 1971). The fact that a greater fall is seen in both post-vagotomy groups when compared with contrast subjects at 60 minutes is probably the result of the greater dilution that occurs in the upper small bowel after a hypertonic meal at this time (Temple *et al.*, 1975). There may also be some direct relationship between sodium and potassium concentration in the jejunum as this is the time period during which sodium concentration is rising very rapidly. Finally, since chloride concentration in the upper small bowel is simply controlled by passive forces (Turnberg, 1973), the gradual rise in concentration of this electrolyte throughout the test period is to be expected.

The intubation technique and the type of meal used in this study were designed to enable the upper small bowel pH and electrolytes to be studied under conditions very close to the physiological state. Despite the known limitations of a single lumen technique, this study has clearly shown that, after truncal vagotomy and drainage, the chyme delivered to the upper small bowel does differ from that in individuals who have not had any gastric operation. The exact alterations in the composition of the jejunal content are, however, dependent upon the completeness of vagal section as judged by the insulin test. Certainly, patients with post-vagotomy diarrhoea have an upper jejunal content entirely similar to post-vagotomy subjects who are diarrhoea free.

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