Radiotelemetering studies of jejunal *pH* before and after vagotomy and pyloroplasty

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Disorders of small bowel function after gastric surgery are well recognized and occur even after vagotomy and drainage procedures (Logan, 1964). Various aetiological factors have been suggested. They include altered motility, inadequate mixing of food and digestive enzymes, diminished pancreatic secretion, and the effect of blind or stagnant loops.

Watson, Watt, Paton, Glen, and Lewis (1966) suggested that changes in *pH* in the small bowel might contribute to disorders of small bowel function after gastric surgery, and investigated changes in jejunal *pH* following gastroenterostomy and total vagotomy, using *pH*-sensitive radio-capsules. A complicating factor in this study was that the position of the recording capsule in the jejunum with respect to the acid and alkaline sources was reversed after operation. This prompted the present study on patients with vagotomy and pyloroplasty, as this operation does not alter the anatomical relationship between the stomach and small bowel.

SUBJECTS

Nine male patients, with typical ulcer histories and radiological findings consistent with chronic duo-

denal ulceration, were studied before and six to eight weeks after pyloroplasty and total vagotomy. In each case the diagnosis of chronic duodenal ulcer was confirmed at operation. The ages of these nine patients ranged from 27 to 66 years, with a mean age of 41.

Five other patients, in whom preoperative *pH* telemetering was performed, were excluded from the study since the capsule would not pass through the pylorus after operation.

METHODS

The Heidelberg (Telefunken) *pH* sensitive capsule and radiotelemetering apparatus have been described and evaluated by Connell and Waters (1964) and Watson and Paton (1965).

The capsule was swallowed after an overnight fast, and recording begun at approximately midday.

The investigational procedure was carried out in the same sequence in each patient. Continuous *pH* records were taken during the transit of the capsule from the oesophagus to the small bowel where it was tethered within the first 15 cm of the jejunum. (Radiological monitoring was used to ensure correct siting in each case.) Once the capsule had reached the proximal jejunum recordings were taken for 90 minutes. Thereafter secretin (Boots) was given intravenously in a maximum body

FIG. 1. Preoperative transit *pH* record from stomach to jejunum in a fasting patient.

weight dose of 1.5 units/kg, and recording continued for a further 45 minutes. The final procedure was the infusion of 10 ml N/10 hydrochloric acid through the tether tube into the jejunum, and this was repeated 15 minutes later. Tracings were continued until the pH record returned to a stable state, and the capsule was finally recovered for recalibration.

The pH records were analysed for (1) transit pH patterns; (2) lowest and highest spontaneous jejunal pH, and the percentage of time spent at or above pH 5, 6, and 7; (3) frequency of jejunal acid and alkaline waves; (4) maximum pH change following intravenous secretin; and (5) response of jejunal pH to duplicate infusion of hydrochloric acid.

RESULTS

1 TRANSIT pH PATTERNS The capsule initially registered high pH levels (> 7) from the oesophagus, which soon fell to low levels (pH 1.5-2) as it entered the stomach. On passing into the first part of the duodenum wide fluctuations in pH occurred (Fig. 1). Similar findings have been reported by Rhodes and Prestwich (1966) who used pH electrodes sited in the duodenal bulb, and ascribed these changes to regurgitation of alkaline pancreatic secretions from the second part of the duodenum and the intermittent onward passage of acid gastric secretions. In the distal duodenum the basal pH was near neutral but frequent acid waves were still seen.

Preoperatively the capsule reached the duodenum about 60 to 90 minutes after it was swallowed.

Following vagotomy and pyloroplasty much longer times were required, presumably as a result of gastric atony.

2 JEJUNAL pH RANGE Figures 2 and 3 illustrate representative tracings in the tethered jejunal position from two patients before and after operation. In the preoperative record in Fig. 2 there are frequent acid dips, and also occasional smaller abrupt changes in pH in an alkaline direction. Following operation the mean jejunal pH has shifted to a higher level, acid waves have disappeared, but alkaline waves persist. Figure 3 demonstrates a similar preoperative tracing, but after operation jejunal pH remains at a relatively constant level, and is undisturbed by changes either in an acid or more alkaline direction.

The lowest and highest spontaneous pH readings in the tethered jejunal position before and after operation are given in Table I. The mean lowest preoperative pH level of 4.6 is significantly lower than the mean lowest postoperative level of 6.3 ($t = 4.82$; $P < 0.005$). The mean highest preoperative pH (6.9) and postoperative pH (7.0) levels do not differ significantly ($t = 0.63$; $P > 0.5$).

These figures, however, give little indication of the overall mean pH. A measure of this was obtained by calculating the percentage time during which the jejunal pH was at or above pH levels of 5, 6, and 7 (Table II). After operation the time spent at or above each of these levels increases. At pH 6 and

FIG. 2. Preoperative tracing from a resting jejunum showing frequent acid dips and occasional alkaline waves (duodenal ulcer). In the postoperative record acid dips are abolished but small alkaline waves persist.

FIG. 3. Both acid and alkaline waves are observed in the pre-operative record, but neither are present after operation.

TABLE I

LOWEST AND HIGHEST SPONTANEOUS JEJUNAL pH BEFORE AND AFTER OPERATION

Preoperative		Postoperative	
Lowest	Highest	Lowest	Highest
4.8	7.6	6.2	7.0
4.4	7.3	6.2	7.0
5.4	7.0	6.0	6.5
5.1	7.3	6.4	7.2
6.0	7.2	6.3	7.0
3.2	6.8	6.8	7.5
3.5	6.4	5.9	7.0
5.3	6.6	6.6	7.6
3.3	6.3	6.2	6.8
Mean	4.6	6.3	7.0
S.D.	1.01	0.45	0.33

Paired comparison of lowest jejunal pH before and after operation
 $n = 8$; $t = 4.82$; $P < 0.005$

Paired comparison of highest jejunal pH before and after operation
 $n = 8$; $t = 0.63$; $P > 0.5$

over the change from 70% of the time before operation to 100% afterwards is significant ($t = 2.77$; $P < 0.05$).

3 FREQUENCY OF JEJUNAL ACID AND ALKALINE WAVES Acid and alkaline waves extend at least to the first few inches of the jejunum. The frequency of these waves has been calculated as the maximum number of distinct pH dips or rises in a complete hour of continuous recording. As movement of the capsule can produce small artefactual changes in the pH record, variations of less than 0.2 pH units were disregarded.

TABLE II

TIME JEJUNAL pH IS AT AND ABOVE pH 5, 6, AND 7 BEFORE AND AFTER OPERATION

Time (min per hour)							
Preoperative				Postoperative			
pH	5 +	6 +	7 +	pH	5 +	6 +	7 +
	60	56	12		60	60	0
	59	56	2		60	60	0
	60	54	4.5		60	60	0
	60	57	6		60	60	16.5
	54	38	0		60	60	15
	58	12.5	0		60	59	0
	60	33	0		60	60	59.5
	40.5	9	0		60	60	0
	60	60	11		60	60	1.5
Mean	56.8	41.7	3.9		60	59.8	10.3
%	94.6	69.5	6.5	100		99.8	17.1

Paired comparison before and after operation of time spent at and above following pH levels

pH 5+ $n = 8$; $t = 1.48$; $P > 0.1$

pH 6+ $n = 8$; $t = 2.77$; $P < 0.05$

pH 7+ $n = 8$; $t = 0.88$; $P > 0.2$

Operation had no effect on the frequency of alkaline waves (Table III), but resulted in a significant reduction, from seven to less than one, in the frequency of acid surges ($t = 10.8$; $P < 0.001$).

4 JEJUNAL pH AFTER SECRETIN The results are shown graphically in Figure 4. There was no significant difference in the secretin response as measured by the maximal pH rise before and after pyloroplasty and vagotomy.

There was a variable time interval before the

TABLE III

FREQUENCY OF JEJUNAL ACID AND ALKALINE WAVES PER HOUR

Preoperative		Postoperative	
Acid	Alkaline	Acid	Alkaline
6	2	2	1
4	3	0	0
5	3	0	0
8	5	1	1
6	2	0	4
6	1	0	7
8	6	0	12
9	6	3	2
9	3	0	2
Mean	6.7	0.7	3.2
S.D.	1.8	0.89	3.96

Paired comparison of frequency jejunal acid waves before and after operation

$$n = 8; t = 10.8; P < 0.001$$

Paired comparison of frequency jejunal alkaline waves before and after operation

$$n = 8; t = 0.169; P > 0.5$$

effect of secretin on jejunal pH was observed. In some patients a fairly steep rise in pH occurred after secretin (Fig. 5) while in others it was more gradual.

5 JEJUNAL pH AFTER ACID INFUSION After infusion of acid there is a rapid fall in pH to low levels (1-2), followed by a gradual return to the preinfusion pH level. The response of the small bowel to this

TABLE IV

RESULTS OF DUPLICATE INFUSIONS OF 1MEQ HCL EXPRESSED AS TIME (MIN) FOR RETURN TO WITHIN 0.5 pH UNIT OF STARTING LEVEL

Preoperative			Postoperative		
First Infusion	Second Infusion	Mean	First Infusion	Second Infusion	Mean
5.5	5.0	5.3	6.75	9.0	7.9
8.0	8.25	8.1	9.0	8.25	8.6
10.5	9.5	10.0	14.25	15.0	14.6
4.25	3.75	4.0	6.0	4.5	5.3
6.0	5.0	5.5	3.0	7.0	5.0
5.75	5.5	5.6	4.5	4.5	4.5
3.0	4.5	3.8	3.0	3.0	3.0
4.5	5.25	4.9	6.75	6.5	6.6
3.5	3.75	3.6	5.25	9.0	7.1
Overall mean	5.64		Overall mean	6.95	
S.D.	2.12		S.D.	3.36	

Paired comparison of mean times before and after operation

$$n = 8; t = 2.0; P > 0.05$$

acid infusion was measured by the time in minutes taken for jejunal pH to return to within 0.5 of the starting level (Table IV). The mean of the duplicate readings was compared before and after operation, and no significant difference was found ($t = 2.0$; $P > 0.05$).

DISCUSSION

Using the Heidelberg radiotelemetering capsule it has been possible to study pH levels in the same segment of proximal jejunum before and after total vagotomy and pyloroplasty.

These studies have shown that after operation the mean lowest pH level of the upper jejunum rises significantly, that there is a significant increase in the time during which jejunal pH is at or above pH 6, and that there is a striking reduction in the number of acid waves. These results are similar to those obtained in patients before and after gastroenterostomy, and are explained by the diminished gastric secretion and gastric atony produced by vagotomy.

We have been unable to confirm our previous finding of an apparent reduction in response to secretin after vagotomy and gastroenterostomy. In the earlier study the pre- and postoperative situations were not strictly comparable. Before operation the source of pancreatic secretions was nearer the recording capsule than the acid source, while after gastroenterostomy the reverse was true. This complicating factor was absent from the present study and the results indicate that total vagotomy has no effect on the secretin-induced secretory response of the pancreas, at least within the early

FIG. 4. Graph of maximal change in jejunal pH following intravenous secretin, before and after operation.

Paired comparison of secretin responses before and after operation

$$n = 8; t = 0.51; P > 0.5$$

FIG. 5. Secretin effect on jejunal pH. Record shows latent period following injection before change in pH is observed.

(six to eight weeks) postoperative period. The observation that the frequency of jejunal alkaline waves is unchanged after operation suggests that vagotomy does not interfere with resting pancreatic secretion.

Intrajejunal infusion of acid and measurement of the neutralization time as a measurement of jejunal buffering capacity was suggested by the technique of intragastric titration of alkali using the radio-capsule introduced by Noller (1962) and Connell and Waters (1964). However, it is likely that with intrajejunal infusions much of the acid is swept away from the recording zone, and that the neutralization time is more a measure of small bowel motility than of buffering capacity.

Although significant changes in the range of jejunal pH take place after vagotomy and drainage procedures, the mean jejunal pH both before and after operation remains between 6 and 7. This level is of the same order as the pH of the upper small intestine in normal individuals which is usually slightly acid at about pH 6.5.

The pH optima for pancreatic and intestinal enzymes range from 6.5 to 8.5. Thus the results of the present investigation, together with our previous studies (Watson *et al*, 1966), show that the changes in jejunal pH occurring after vagotomy and drainage procedures are in a direction likely to enhance rather than inhibit the physiological processes of digestion and absorption, and are unlikely to contribute to the disorders of small bowel function observed after these operations.

SUMMARY

Jejunal pH was studied by radiotelemetry in nine males which chronic duodenal ulcer before and six to eight weeks after total vagotomy and pyloroplasty.

After operation the mean lowest jejunal pH rose significantly from 4.6 to 6.3, there was a significant increase in the percentage time jejunal pH was at or above pH 6, and a significant reduction in the frequency of acid waves.

There was no change in the frequency of alkaline waves following operation, in the response to intrajejunal infusion of acid, or in the pH rise following intravenous secretin.

These findings are discussed.

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