Radiotelemetering studies of jejunal pH before and after vagotomy and gastro-enterostomy

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EDITORIAL SYNOPSIS These radiotelemetering studies have clearly shown that there is a rise in the jejunal pH after total vagotomy and posterior gastro-enterostomy and that acid surges no longer took place.

With the development of radio-transmitting pH-sensitive capsules (Jacobson and Mackay, 1957; Nöller, 1961), the study of pH changes in the gastro-intestinal tract has been greatly facilitated, and once inaccessible regions can now be investigated. Disorders of small bowel function producing malabsorption and diarrhoea are not uncommon after gastric surgery and are due to such factors as diminished pancreatic secretion, inadequate mixing of food and digestive enzymes, and intestinal hypermotility. It is possible that pH studies may shed some light on this difficult subject.

It has not previously been feasible to compare jejunal pH before and after surgery, and the alterations in jejunal pH produced by surgery have not been recorded. In the present investigation, alterations in jejunal pH after vagotomy and gastro-enterostomy have been studied, using experimental techniques previously described (Watson and Paton, 1965).

METHODS

Twelve male patients, aged from 29 to 60 years, were studied before and six to eight weeks after total vagotomy and posterior gastro-enterostomy. A histamine test meal (Kay, 1953) was performed before operation and the diagnosis of chronic duodenal ulcer was confirmed at operation.

Each series of recording was begun at approximately 12 noon, about four hours after a light breakfast of tea and one slice of bread, butter, and marmalade.

Before operation, observations were made while the pH capsule passed through the stomach and duodenum, and it was then tethered within the first 15 cm. of jejunum (Fig. 1, I). After operation, this portion of jejunum is much nearer the source of acid which now reaches it via the stoma. Accordingly, in eight patients the capsule was

tethered at a distance of 5 to 10 cm. from the stoma, that is, in the same segment from which pre-operative readings were taken (Fig. 1, IIa), and, in the other four patients, the capsule was sited 35 to 40 cm. beyond the stoma (Fig. 1, IIb) so that it would be at a distance from the acid source equivalent to the pre-operative position.

By this means, it was possible to compare pH records from the same segment of jejunum before and after operation and also to compare segments approximately equidistant from the stomach. The recordings from these two postoperative locations were so comparable that they have been considered together in the analysis of data.

The separate stages of each recording were carried out in strict sequence. Continuous pH records were taken during the transit of the capsule from the mouth to the

FIG. 1. Positions of telemetering capsules.
I In first 15 cm. of jejunum before operation.
IIa 5 to 10 cm. from stoma, and
IIb 35 to 40 cm. from stoma, after operation.

small bowel, interrupted only for radiological monitoring, and recording in the tethered position continued for a further 90 to 120 minutes. Thereafter, in eight of the 12 patients, a maximum body weight dose of secretin was given intravenously. After a suitable interval, 10 ml. of N/10 hydrochloric acid was infused rapidly through the tether tubing, and this was repeated 15 minutes later.

After a further 30 minutes the patient was given light afternoon tea and recordings were continued either until the capsule ceased to transmit or until it was recovered for final calibration.

The pH records were studied for the following data: (a) transit pH patterns, (b) lowest and highest spontaneous jejunal pH, (c) frequency of jejunal acid waves, (d) maximum pH change following intravenous secretin, and (e) pH change following acid infusion.

RESULTS

At the time of the repeat study, 11 patients were completely satisfied with the operation and had no symptoms. The twelfth had had one episode of mild diarrhoea two weeks previously.

TRANSIT pH PATTERNS The pH readings during the progress of the capsule from the oesophagus to the first part of the duodenum showed the expected changes from high levels (> 7) in the oesophagus to low levels (pH 1-2) in the stomach (Fig. 2). On entering the first part of the duodenum rapid fluctuation of levels occurred, and it is difficult to say whether acid or near neutral pH levels are the normal findings in this area.

In the second part of the duodenum (Fig. 3), the basal pH is near neutral, but there are still frequent and substantial acid waves.

In the distal duodenum (Fig. 4), the record shows the classical physiological sequence of an acid bolus followed after an interval by a secretin-stimulated bolus of pancreatic juice. The wave forms correspond with those which are produced experimentally by acid infusion and intravenous secretin (Watson and Paton, 1965).

In none of the postoperative studies did the capsule enter the afferent loop, and we have no information about the effect of operation on pH in the duodenal

FIG. 2. Pre-operative transit pH record from oesophagus to first part of duodenum. The patient was fasting.

FIG. 3. Pre-operative pH record from second part of duodenum, with the patient fasting.

FIG. 4. Pre-operative pH record from distal duodenum showing a sequence of acid bolus followed after an appropriate interval by a bolus of pancreatic juice.

loop. However, from other data, we think it likely that the pH sequences just described will either have been abolished or significantly modified.

JEJUNAL pH RANGE The lowest and highest spontaneous pH readings in the tethered jejunal positions, before and after operation, are given in Table I.

TABLE I

LOWEST AND HIGHEST SPONTANEOUS JEJUNAL pH BEFORE OPERATION (POSITION I) AND AFTER OPERATION AT POSITION IIA (FIRST EIGHT SUBJECTS) AND IIB (LAST FOUR SUBJECTS)¹ pH

Pre-operative		Postoperative	
Lowest	Highest	Lowest	Highest
3.3	7.0	5.6	6.2
4.0	6.6	6.0	7.0
5.1	6.4	5.3	6.0
4.1	6.2	4.8	7.0
2.0	6.5	4.0	6.0
2.0	5.5	5.6	6.8
3.0	5.8	5.6	6.8
4.3	6.5	5.6	6.0
2.6	7.5	5.4	6.8
2.3	5.6	3.8	7.2
2.0	6.0	3.5	6.5
2.4	8.0	5.6	6.3
Mean	3.1	5.1	6.5
S.D.	0.46	0.83	0.44

¹All postoperative readings are taken together for statistical analysis.

Readings related to secretin injections or acid infusions are not included.

The mean lowest pre-operative pH level of 3.1 is significantly lower than the mean lowest postoperative level of 5.1 ($t = 5.17$; $p < 0.001$). The mean highest pre- and postoperative pH levels are both 6.5, but the postoperative figures are more closely ranged about the mean (6.0-7.2) than the pre-operative (5.5-8.0).

FREQUENCY OF ACID WAVES REACHING THE JEJUNUM Acid surges may extend at least as far as the first few inches of jejunum (Fig. 5). The frequency of these acid waves has been calculated as the maximum number of distinct pH dips in any one complete hour of continuous recording in the period before the administration of secretin, with the capsule in its tethered position. Before operation these acid waves were present in 11 of the 12 patients, and their frequency ranged from 1 to 27 per hour, with a mean frequency of 15 per hour for the 11 subjects. After operation, acid surges were absent and this is the principal cause of the rise in the mean lowest jejunal pH which occurred after operation.

JEJUNAL pH AFTER SECRETIN Secretin studies were initiated only when the jejunal pH was in a relatively stable phase and the results are given in Table II.

FIG. 5. Pre-operative pH record showing numerous acid waves in the first few inches of jejunum.

TABLE II

MAXIMAL CHANGE IN JEJUNAL pH AFTER INTRAVENOUS SECRETIN¹

pH					
Pre-operative			Postoperative		
Before Secretin	After Secretin	Rise	Before Secretin	After Secretin	Rise
5.8	6.5	0.7	4.8	6.0	1.2
5.2	6.5	1.3	6.7	7.6	0.9
5.5	7.0	1.5	5.3	6.0	0.7
6.0	6.5	0.5	6.2	6.7	0.5
6.2	7.5	1.3	6.8	6.5	0.7
5.0	6.2	1.2	6.4	4.5	-1.9
5.2	6.4	1.2	6.5	7.0	0.5
8.0	8.5	0.5	5.8	6.0	0.2
Mean 5.86	6.89	1.03	5.94	6.29	0.35

¹The first four pairs of postoperative results are from the IIa position, the second four from the IIb position.

These show an apparent reduction in the pH rise following intravenous secretin, but the pre- and post-operative figures cannot really be compared, because before operation the source of pancreatic secretion is nearer the capsule than the acid source, whereas after operation the reverse applies.

If similar results showing a low pH rise after secretin were obtained with the capsule placed in the afferent loop, they would suggest that there is a significant reduction in the secretory capacity of the pancreas following operation.

JEJUNAL pH AFTER ACID INFUSION Figure 6 illustrates the types of responses obtained by duplicate intra-jejunal infusions of 1 mEq. of hydrochloric acid. This response was measured quantitatively by planimetry of the area of the curve. The area of the acid curve may be altered by operation, and because the area of the curve varies inversely with the jejunum's ability to restore the pre-existing pH, any postoperative increase in area shows impaired 'buffering capacity' of the jejunum.

Satisfactory duplicate studies before and after operation were obtained in 10 patients and are listed in Table III. The numbers refer to planimetric units of area.

There is no significant difference between the duplicate readings before operation. Postoperatively there is a significant difference ($t = 2.45$; $p < 0.05$) between the results obtained from the two infusions of acid. This appears to be due to the low first reading and does not suggest any deterioration in the buffering reserve of the jejunal segment, as the area of the second infusion does not differ significantly from the pre-operative results.

MISCELLANEOUS OBSERVATIONS The wave-like form of the pH curve seen after food in the pre-operative

FIG. 6. Types of curve obtained by duplicate intra-jejunal infusion of 1 mEq. of HCl.

TABLE III

RESULTS OF DUPLICATE INFUSIONS OF 1 M.EQ. OF HYDROCHLORIC ACID EXPRESSED AS PLANIMETRIC UNITS OF AREA OF THE pH CURVE¹

Pre-operative		Postoperative	
First Infusion	Second Infusion	First Infusion	Second Infusion
23	73	31	17
20	20	20	29
34	38	32	36
15	32	16	52
59	26	42	70
23	69	10	26
35	25	22	32
24	23	31	45
64	31	19	42
42	34	25	35
Mean 33.9	37.1	24.8	38.4
S.D. 16.8	18.7	9.3	15.1

¹The first seven pairs of postoperative results are from the IIa position, the last three from the IIb position.

FIG. 7. Post-prandial jejunal pH records showing effect of surgery.

TABLE IV

BASAL AND MAXIMUM ACID OUTPUT (M.A.O.), FREQUENCY OF JEJUNAL pH DIPS, LOWEST SPONTANEOUS JEJUNAL pH, AND UNITS OF BUFFERING CAPACITY IN NINE SUBJECTS PRE-OPERATIVELY¹

Gastric Acid Output (mEq./hr.)		Jejunal Acid Waves (pH dips/hr.)	Lowest Jejunal pH	Jejunal Buffering Capacity	
Basal	Maximum 2 × (15 - 45 min.)			I	II
3	11	12	4.1	15	32
2	13	19	4.0	20	20
6	20	1	2.3	64	31
6	33	11	2.0	59	26
6	34	0	4.2	49	52
9	49	13	2.0	8	25
1	52	27	2.6	24	23
8	53	6	2.0	23	69
10	63	20	3.3	23	73

¹The results are arranged in sequence of rising M.A.O. Acid figures are given to the nearest whole number.

subject is replaced by a smooth curve following operation (Fig. 7).

In Table IV are shown together for analysis the basal and maximum acid output (M.A.O.), number of pH dips per hour, lowest jejunal pH, and jejunal buffering capacity, all pre-operatively, in nine patients for whom all data are complete. They are listed in sequence of rising maximum acid output.

After preliminary plotting of various combinations of results, only three pairings seemed to require formal statistical analysis. Comparing M.A.O. and

frequency of jejunal pH dips, $r = 0.378$ and $p > 0.1$. Comparing M.A.O. and lowest spontaneous jejunal pH, $r = -0.46$ and $p > 0.1$. Comparing M.A.O. and the second set of figures for buffering capacity of jejunum, $r = 0.567$ and $p > 0.1$.

It seems clear that there is no directly significant relationship between gastric acid output alone and jejunal acidity. However, it is possible, and perhaps likely, that if the factor of gastro-duodenal motility could be included in the analysis, a significant relationship would begin to emerge.

DISCUSSION

Using the Heidelberg capsule, it has been possible to study pH levels in comparable segments of jejunum before and after total vagotomy and gastro-enterostomy.

The most significant observation is that the mean lowest pH level of the upper jejunum rises significantly after operation (Table I) and that acid waves, which are a frequent pre-operative feature, disappear completely. This can be attributed to the diminished gastric secretion and gastric hypomotility produced by vagotomy.

The absence of acid waves postoperatively suggests that there may be a partial or complete loss of the acid-secretin mechanism which stimulates the flow of pancreatic juice, and this may explain the abnormalities of fat absorption which are a well recognized complication of any duodenal bypass procedure. It is possible that the secretin-producing capacity of the duodenal loop may be diminished by the by-pass but no evidence has been obtained as to whether the maximum secretory capacity of the pancreas is affected by this type of surgery.

The results of previous clinical work on this problem are conflicting. Dreiling, Druckerman, and Hollander (1952) found no reduction in secretin-provoked pancreatic secretion in a group of eight totally vagotomized patients, whereas Shingleton, Anlyan, and Hart (1952), who studied a group of 10 such patients, found a significant reduction. The latter authors studied patients an average of four years and eight months after operation. The former authors do not record the time interval. Neither group studied the same subjects before as well as after operation.

The experiments of Bastable (1965) in dogs demonstrate no immediate effect of vagotomy on secretin-provoked pancreatic secretion. But his post-vagotomy studies are likely to be much too soon after operation to demonstrate an effect which is more likely to be due to involutional hypofunction secondary to chronic hypostimulation than to acute denervation.

The mean highest pH level is unchanged after operation (Table I), and no evidence of impairment of the buffering capacity of the jejunal segment was found (Table III). There is, therefore, no evidence of small bowel dysfunction postoperatively in these patients. However, all 12 appeared to have obtained a good result from operation, so far as observation extends, and these data may establish a suitable comparative basis for the study of those patients who develop intestinal dysfunction after vagotomy and gastro-enterostomy.

SUMMARY

Jejunal pH was studied by radiotelemetering in 12 males with chronic duodenal ulcer before and six to eight weeks after total vagotomy and posterior gastro-enterostomy.

After operation the mean lowest jejunal pH rose significantly from 3.1 to 5.1, and acid surges, which

were present in 11 of the subjects before operation, disappeared.

The buffering capacity of the jejunum was not impaired. The pH rise which normally follows intravenous secretin was apparently reduced.

REFERENCES

- Bastable, J. R. G. (1965). Vagotomy and pancreatic secretion. *Brit. J. Surg.*, **52**, 459-464.
- Dreiling, D. A., Druckerman, L. J., and Hollander, F. (1952). The effect of complete vagisection and vagal stimulation on pancreatic secretion in man. *Gastroenterology*, **20**, 578-586.
- Jacobson, B., and Mackay, R. S. (1957). A pH-endoradiosonde. *Lancet*, **1**, 1224.
- Kay, A. W. (1953). Effect of large doses of histamine on gastric secretion of HCl. An augmented histamine test. *Brit. med. J.*, **2**, 77-80.
- Nöller, H. G. (1961). Clinical applications of telemetering techniques. In *Proceedings of the IIIrd International Conference on Medical Electronics, Institution of Electrical Engineers, London*, p. 111-114.
- Shingleton, W. W., Anlyan, W. G., and Hart, D. (1952). The diagnosis of pancreatic disorders by certain laboratory procedures. *Ann. Surg.*, **136**, 578-584.
- Watson, W. C., and Paton, E. (1965). Studies on intestinal pH by radiotelemetering. *Gut*, **6**, 606-612.