Gut, 1968, **9**, 612-616

Radiotelemetering studies of jejunal *p*H before and after vagotomy and pyloroplasty

J. D. MAXWELL, W. C. WATSON, J. K. WATT, AND A. FERGUSON

From the University Department of Medicine and the Surgical Division, Royal Infirmary, Glasgow

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 *p*H in the small bowel might contribute to disorders of small bowel function after gastric surgery, and investigated changes in jejunal *p*H following gastroenterostomy and total vagotomy, using *p*H-sensitive radiocapsules. 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 duodenal 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 *p*H telemetering was performed, were excluded from the study since the capsule would not pass through the pylorus after operation.

METHODS

The Heidelberg (Telefunken) *p*H 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 *p*H 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

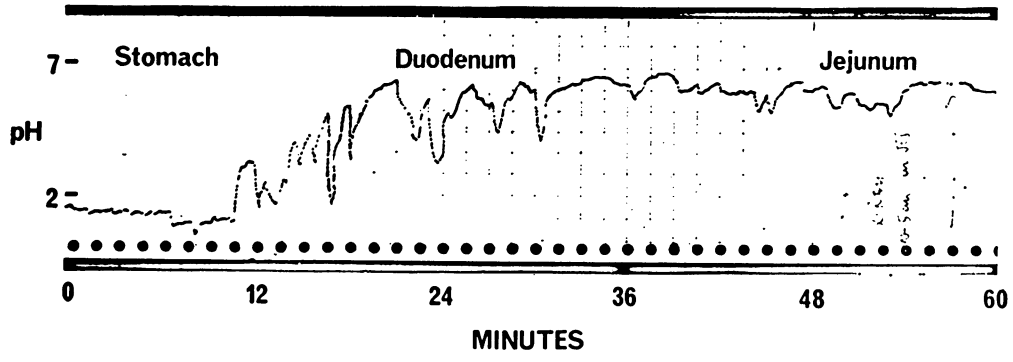

FIG. 1. *Preoperative transit* p*H record from stomach to jejunum in a fasting patient.*

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 *p*H record returned to a stable state, and the capsule was finally recovered for recalibration.

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

RESULTS

1 TRANSIT *p*H PATTERNS The capsule initially registered high *p*H levels (> 7) from the oesophagus, which soon fell to low levels (*p*H 1·5-2) as it entered the stomach. On passing into the first part of the duodenum wide fluctuations in *p*H occurred (Fig. 1). Similar findings have been reported by Rhodes and Prestwich (1966) who used *p*H 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 *p*H 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 *p*H 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 *p*H in an alkaline direction. Following operation the mean jejunal *p*H 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 *p*H remains at a relatively constant level, and is undisturbed by changes either in an acid or more alkaline direction.

The lowest and highest spontaneous *p*H readings in the tethered jejunal position before and after operation are given in Table I. The mean lowest preoperative *p*H level of 4·6 is significantly lower than the mean lowest postoperative level of 6·3 ($t = 4{\cdot}82$; $P < 0{\cdot}005$). The mean highest preoperative *p*H (6·9) and postoperative *p*H (7·0) levels do not differ significantly ($t = 0{\cdot}63$; $P > 0{\cdot}5$).

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

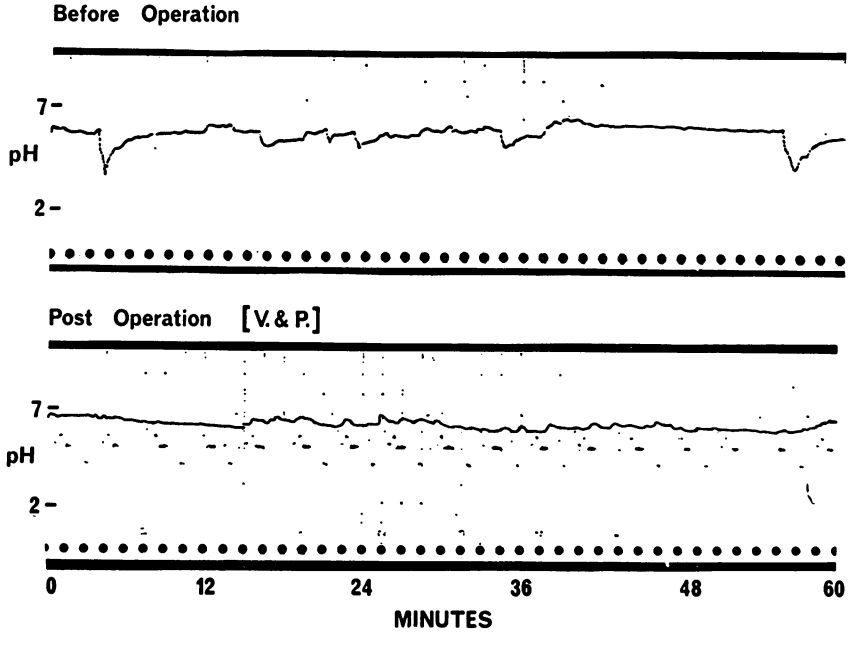

FIG. 2. *Preoperative tracing from a resting jejunum showing frequent acid dips and occasional alkaline waves (duodenal ulcer). In the postoperative record acid dips are abolished but small alkaline waves persist.*

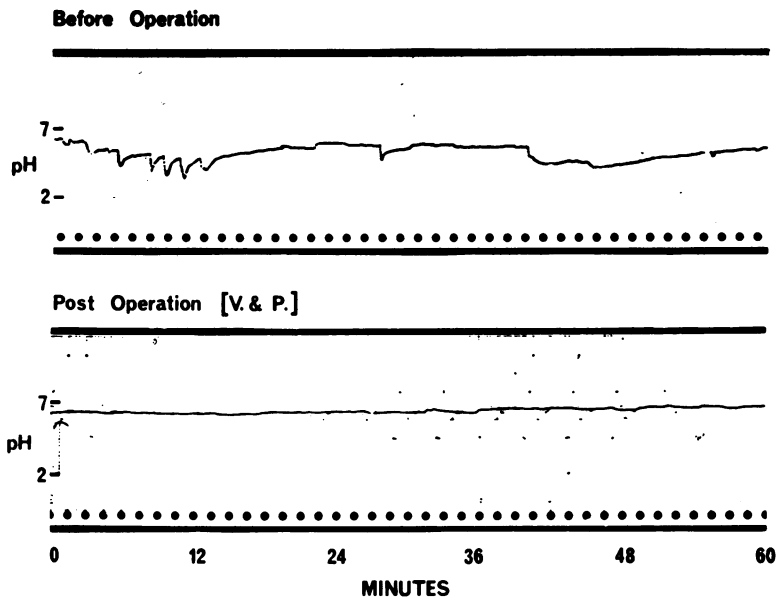

FIG. 3. *Both acid and alkaline waves are observed in the pre-operative record, but neither are present after operation.*

TABLE I

LOWEST AND HIGHEST SPONTANEOUS JEJUNAL *p*H 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	6·9	6·3	7·0
S.D.	1·01	0·45	0·28	0·33

Paired comparison of lowest jejunal *p*H before and after operation
$n = 8; t = 4{\cdot}82; P < 0{\cdot}005$
Paired comparison of highest jejunal *p*H before and after operation
$n = 8; t = 0{\cdot}63; P > 0{\cdot}5$

TABLE II

TIME JEJUNAL *p*H IS AT AND ABOVE *p*H 5, 6, AND 7 BEFORE AND AFTER OPERATION

	Time (min per hour)					
	Preoperative			*Postoperative*		
*p*H	5+	6+	7+	*p*H 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 a and above following *p*H levels
*p*H 5+ $n = 8; t = 1{\cdot}48; P > 0{\cdot}1$
*p*H 6+ $n = 8; t = 2{\cdot}77; P < 0{\cdot}05$
*p*H 7+ $n = 8; t = 0{\cdot}88; P > 0{\cdot}2$

over the change from 70% of the time before operation to 100% afterwards is significant ($t = 2{\cdot}77$; $P < 0{\cdot}05$).

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 *p*H dips or rises in a complete hour of continuous recording. As movement of the capsule can produce small artefactual changes in the *p*H record, variations of less than 0·2 *p*H units were disregarded.

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 ($t = 10{\cdot}8$; $P < 0{\cdot}001$).

4 JEJUNAL *p*H AFTER SECRETIN The results are shown graphically in Figure 4. There was no significant difference in the secretin response as measured by the maximal *p*H 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	3·4	0·7	3·2
S.D.	1·8	1·8	0·89	3·96

Paired comparison of frequency jejunal acid waves before and after operation

$n = 8; t = 10{\cdot}8; P < 0{\cdot}001$

Paired comparison of frequency jejunal alkaline waves before and after operation

$n = 8; t = 0{\cdot}169; P > 0{\cdot}5$

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

$n = 8; t = 2{\cdot}0; P > 0{\cdot}05$

effect of secretin on jejunal *p*H was observed. In some patients a fairly steep rise in *p*H 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 *p*H to low levels (1-2), followed by a gradual return to the preinfusion *p*H level. The response of the small bowel to this acid infusion was measured by the time in minutes taken for jejunal *p*H 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 ($t = 2{\cdot}0$; $P > 0{\cdot}05$).

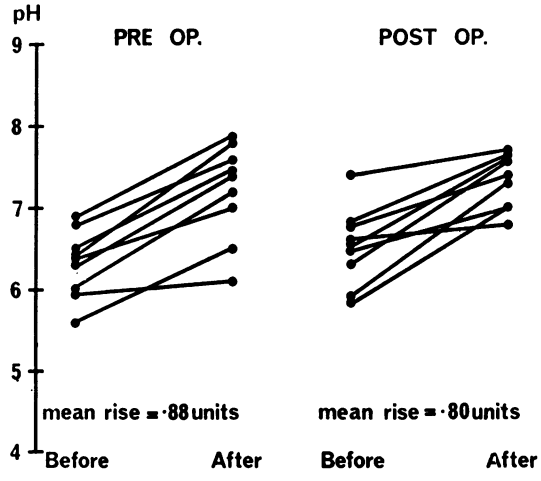

FIG. 4. *Graph of maximal change in jejunal pH following intravenous secretin, before and after operation.*
Paired comparison of secretin responses before and after operation
$n = 8; t = 0{\cdot}51; P > 0{\cdot}5$.

DISCUSSION

Using the Heidelberg radiotelemetering capsule it has been possible to study *p*H 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 *p*H level of the upper jejunum rises significantly, that there is a significant increase in the time during which jejunal *p*H is at or above *p*H 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

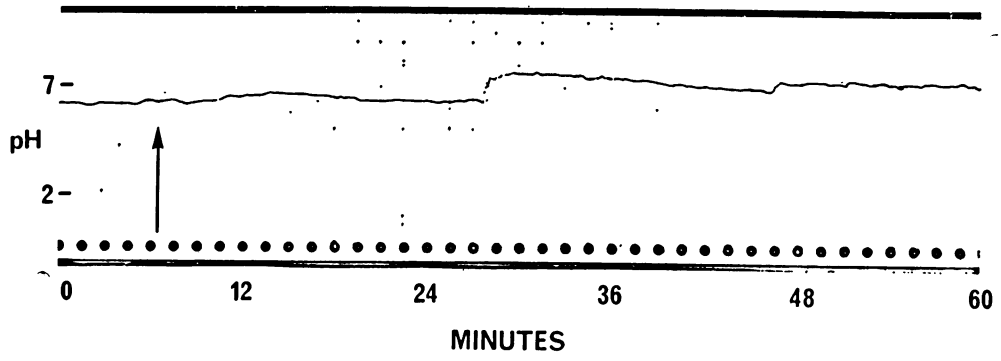

FIG. 5. *Secretin effect on jejunal* pH. *Record shows latent period following injection before change in* pH *is observed.*

(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 *p*H take place after vagotomy and drainage procedures, the mean jejunal *p*H both before and after operation remains between 6 and 7. This level is of the same order as the *p*H of the upper small intestine in normal individuals which is usually slightly acid at about *p*H 6·5.

The *p*H 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 *p*H 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 *p*H was studied by radiotelemetering in nine males which chronic duodenal ulcer before and six to eight weeks after total vagotomy and pyloroplasty.

After operation the mean lowest jejunal *p*H rose significantly from 4·6 to 6·3, there was a significant increase in the percentage time jejunal *p*H was at or above *p*H 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 *p*H rise following intravenous secretin.

These findings are discussed.

We wish to thank Professor E. M. McGirr for his interest and encouragement. The study was carried out while J. D. Maxwell was the McIntyre Research Scholar at Glasgow Royal Infirmary.

REFERENCES

Connell, A. M., and Waters, T. E. (1964). Assessment of gastric function by *p*H telemetering capsule. *Lancet*, **2**, 227-230.

Logan, H. (1964). Steatorrhoea and diarrhoea after vagotomy: a comparison of drainage procedures. *Gut*, **5**, 188-191.

Noller, H. G. (1962). Ergebnisse der Magenfunktionsermittlung mit der EndoradioKapsel. *Fortschr. Med.*, **80**, 351-355.

Rhodes, J., and Prestwich, C. J. (1966). Acidity at different sites in the proximal duodenum of normal subjects and patients with duodenal ulcer. *Gut*, **7**, 509-514.

Watson, W. C., and Paton, E. (1965). Studies on intestinal *p*H by radiotelemetering. *Ibid.*, **6**, 606-612.

——, Watt, J. K., Paton, E., Glen, A., and Lewis, G. J. T. (1966). Radiotelemetering studies of jejunal *p*H before and after vagotomy and gastro-enterostomy. *Ibid.*, **7**, 700-705.