Studies on intestinal pH by radiotelemetering

W. C. WATSON AND E. PATON

From the University Department of Medicine, Royal Infirmary, Glasgow

EDITORIAL SYNOPSIS The pH of the proximal jejunum has been studied by radiotelemetering.

Data on the pH range in the fasting subject and in response to food, intravenous secretin, and infusions of dilute hydrochloric acid have been reported.

The development of radiotransmitting pH-sensitive capsules (Jacobson and Mackay, 1957; Noller, 1960) has provided a new technique for the measurement of pH within the gastrointestinal tract. Noller (1962) and Connell and Waters (1964) have reported their experiences with this technique in the measurement of gastric acid secretion. Connell and Waters give a clear description of the working principles of the pH-telemetering apparatus and make a critical appraisal of its accuracy.

In this paper we report our experiences with the apparatus in the measurement of pH within the small bowel.

METHODS

Thirty subjects were studied but in only 20 of them were satisfactory results obtained. The main reason for this was the failure of the Heidelberg capsule to leave the stomach during its effective life span of about six to eight hours. Two patients pulled it up after it had entered the duodenum.

Before activation the capsule was tethered to fine, hollow-bore, radio-opaque, plastic tubing (Portex O/PP 60) marked at 100 cm. intervals and perforated 0.5 cm. from its attachment to the capsule. By taking a straight radiograph of the abdomen and measuring the tubing, the capsule was accurately located in every case. Figure 1 shows a capsule situated in the upper jejunum about 8 cm. beyond the ligament of Treitz and 85 cm. from the teeth. Figure 2 shows a capsule which was measured at 105 cm. from the teeth but with the tubing coiled in the stomach. Figure 3 shows a capsule passing straight through the small bowel to the terminal ileum and measured at 300 cm. from the teeth. This capsule is out of the picture.

The perforation in the tube permitted the injection of fixed volumes of 0.1 N hydrochloric acid, saturated sodium bicarbonate and buffers of known pH, directly into the recording field of the capsule. It was not possible, however, to aspirate jejunal juice through this very narrow-bore tubing. Instead a number of capsules were recovered from the intestine after six hours of recording and rechecked against buffers of known pH.

CALIBRATION OF CAPSULES After activation the capsules

were calibrated in buffers which had been specially standardized at 37°C. These were supplied by Hopkin and Williams Ltd. Buffers from another source were unsatisfactory in that they 'poisoned' the capsule which ceased to transmit. In a number of instances, after the capsule had been calibrated and stabilized at pH 2.0 and 7.0, it was placed in buffers at pH 3, 4, 5, 6, and occasionally 8, as a check against the proportionality of intermediate responses. Faulty capsules were quickly recognized and discarded.

Usually the subjects had little difficulty in swallowing

FIG. 1. Radiograph of pH capsule situated in upper jejunum.

FIG. 2. Radiograph showing radio-opaque tubing coiled up and capsule retained in the stomach.

FIG. 3. Radiograph of tubing in a patient in whom the capsule passed to a distance of 300 cm. from the teeth. The capsule is in the pelvis and is not visible on the radiograph.

the capsules, which thereafter either passed quickly into the duodenum or lingered indefinitely in the stomach, in spite of the standard manoeuvres which may be used to expedite their passage. Sometimes such capsules would enter the duodenum when the patient was given food.

INVESTIGATIONS As far as possible the investigations which will be described were carried out in the same order, but a certain amount of flexibility was necessary to make full use of each study.

First, the fasting pH was recorded over periods of one to three hours. Some subjects were then given a three-course lunch of soup, meat and vegetable, and milk pudding, the courses being spaced to permit about 15 minutes of pH recording after each.

In nine patients the pH response was recorded following the intravenous injection of the maximum test dose of secretin, that is, between 1.0 and 2.0 units per kilogram of body weight. Thereafter, and when a stable pH had again been achieved, 10 ml. of 0.1 N hydrochloric acid (1 mEq.) was injected through the tubing and the subsequent pH responses recorded.

Occasionally small amounts of dilute acid or saturated sodium bicarbonate were injected to test the gross responsiveness of the capsule.

RESULTS

After leaving the stomach the capsule tended to pass quickly into the proximal jejunum. In 17 of the 20 satisfactory studies it remained for the entire transmitting period in a location 80 to 110 cm. from the teeth. In three subjects it passed to distances of 165, 200, and 300 cm. from the teeth. Two of these subjects were thyrotoxic, and the third was a patient with hepatic cirrhosis receiving neomycin.

CAPSULE RESPONSIVENESS The pH response to the injection of dilute acid or bicarbonate was always immediate and appropriate, falling to less than 2.0 or rising to more than 7.0 respectively. Following the injection of buffers a pH reading corresponding closely to that of the buffer was recorded. On rechecking the capsules after retrieving them from the intestine, the maximum pH error was 0.5 pH unit, and usually it was negligible. This agrees closely with the experience of Connel and Waters (1964). The small discrepancies within the intestine are likely to be due to dilution or endogenous buffering.

RANGE AND LEVELS OF pH The fasting pH record is a smooth line, contrasting with the regular wave-like form of the postprandial record (Fig. 4).

The pH levels in 14 subjects recorded over periods of up to four hours, in the proximal jejunum, are given with the clinical diagnoses in Table I. The pH ranges from a mean low of 4.0 ± 0.7 to a mean maximum of 6.0 ± 0.5 . The overall mean is about

FIG. 4. Smooth form of the pH curve in fasting patient (a) and wave-like form after food (b).

TABLE I

RANGE OF pH LEVELS IN PROXIMAL JEJUNUM
OF 14 SUBJECTS STUDIED BY RADIOTELEMETERING
AND THREE OTHER SUBJECTS

Case No.	Diagnosis	pH	
		Lowest	Highest
5	Partial gastrectomy	3.5	6.0
8	Anxiety state	3.1	6.8
9	Normal	4.3	6.3
12	Adult coeliac disease	4.7	6.0
15	Duodenal ulcer	4.2	5.9
19	Proctocolitis	5.0	5.8
20	Proctocolitis	5.0	6.1
22	Adult coeliac disease	3.2	5.9
23	Partial gastrectomy	3.3	6.8
24	Acute gastric erosion	4.0	5.3
27	Gastroenterostomy and vagotomy	3.5	6.0
28	Chronic pancreatitis	4.3	5.1
30	Proctocolitis	3.6	6.2
31	Gastroenterostomy and vagotomy	4.8	5.5
	Mean	4.0 ± 0.7	6.0 ± 0.5

Capsule more than 150 cm. from teeth	{	7	Thyrotoxicosis	3.5	7.0
		14	Cirrhosis and neomycin	5.0	6.3
		21	Thyrotoxicosis	4.0	6.3

5.2. The range of pH varies from 3.7 units (no. 8) to 0.7 units (no. 31). Our data are still too limited for us to comment on whether this variable is of functional significance.

After food the pH ranged between 5.0 and 6.0 irrespective of whether the item of food eaten was savoury or sweet, fat, protein, or carbohydrate. The wave frequency of this curve was about 1 per minute, and the pH variation about 0.5 pH unit. This is greater than might be expected solely on the basis of peristaltic movement of the capsule, which is slightly sensitive to movement, but not by more than 2 to 3 Kc.p.s., equivalent to 0.2 pH unit. The pH variation is likely to be a real one, therefore, and related to pH fluctuations dependent upon rhythmic mixing of gastric chyme and pancreatico-biliary secretions.

SUDDEN SPONTANEOUS ALTERATIONS IN pH In three subjects there was an intermittent, rapid, spontaneous rise in pH, apparently stimulated by a falling pH (Fig. 5). The rise occurred over 10 seconds, and was sustained. This sequence occurred three times in one patient during a period of 40 minutes. It is perhaps of significance that of the three patients showing this pattern two had partial gastrectomies and one a gastroenterostomy and vagotomy. The phenomenon may represent spontaneous intermittent pancreatic secretion, or a pH-triggered release of secretin with similar effects. The observation deserves further study. One of the gastrectomy patients complained of epigastric aching during this time.

pH RESPONSE TO INTRAVENOUS SECRETIN In eight of the nine patients given intravenous secretin the pH rose from a mean of 5.1 to 6.3. An example of this response from an original record is shown in Figure 6 and displayed diagrammatically in Figure 7. There is a relatively constant latent period between the injection of secretin and the change in pH. The curve of the pH response is usually biphasic. The latent period is probably determined by the distance of the capsule from the pancreatic duct and the vigour of the peristaltic waves. Further study of this response may show that it provides additional information about the nature and degree of the secretin response. In particular there may be some significance in the

TABLE II
CHANGE IN JEJUNAL pH FOLLOWING THE
INTRAVENOUS INJECTION OF SECRETIN AND TIME
TO ACHIEVE MAXIMUM RESPONSE

Case No.	Diagnosis	pH		Time (min.)
		Before	After	
12	Adult coeliac disease	4.7	5.8	12.5
19	Proctocolitis	5.0	6.0	8.5
22	Adult coeliac disease	5.1	6.8	25.0
23	Partial gastrectomy	5.2	6.3	9.0
24	Acute gastric erosion	4.7	5.9	11.0
25	Gastroenterostomy and vagotomy	4.2	6.4	30.0
26	Partial gastrectomy	6.7	7.0+	9.5
27	Gastroenterostomy and vagotomy	5.0	5.5	12.0
	Mean	5.1 ± 0.7	6.3 ± 0.6	
21	Cirrhosis and neomycin	5.8	5.1

FIG. 5. Sudden spontaneous rise in pH, repeated after about 30 minutes.

FIG. 6. Working record of the typical biphasic curve of the secretin response.

FIG. 7. Curve of human small bowel pH response following injection of secretin.

time taken for the maximum pH response to be achieved. This varied from 8.5 to 30 minutes in the nine tests reported here, but there is no clue to the reason for this from the small range of disorders covered in the sample.

In one of the nine patients the pH fell slightly. This was a man with hepatic cirrhosis receiving oral neomycin, and the capsule was located well down the jejunum.

pH RESPONSE TO INFUSION OF 0.1 N HYDROCHLORIC ACID Following the infusion of 1 mEq. of hydrochloric acid a pH response curve of remarkable

constancy was obtained. Figure 8 shows an actual record. Figure 9 is a diagrammatic representation illustrating the principal components of the curve.

Within seconds of the infusion the pH falls to levels below 2.0. Very quickly thereafter it begins to return to its starting level and may rise by 3 pH units in about three to five minutes. This is the 'immediate response'. The further adjustment over the remaining 1 or 2 pH units is more gradual. This is the 'delayed response', which taken with the 'pH swing' which sometimes follows it, resembles in some respects the form of the curve following the intravenous injection of secretin.

This pH response to hydrochloric acid is not exactly what might be anticipated on purely chemical grounds. If alkali is added at a constant rate to an acid, the pH rises slowly at first and then quickly swings past neutral. The pH adjustment in the present situation seems to be one of rapid addition of alkali and then a finely graded return to the starting pH. However, speculation about possible secretory responses by the jejunal mucosa would be premature at this stage. It is likely that much of the acid is simply swept away from the recording zone by peristaltic flow.

DISCUSSION

As far as we are aware, there is as yet no published

FIG. 8. Working record of a typical pH curve following the intrajejunal infusion of 1 mEq. of hydrochloric acid.

FIG. 9. Curve of pH response following infusion of $\frac{1}{10}$ N HCl into human small bowel.

work on intestinal pH as studied by the Heidelberg capsule. There has of course been much work done on the pH within the duodenal bulb and second part of the duodenum using special glass electrodes attached by thin cables to standard pH recording equipment. But using the Heidelberg capsule, tethered to very fine radio-opaque tubing, it has been possible to study more distal parts of the bowel with relative ease.

The failure of the capsule to pass into the small bowel in one third of our patients was frustrating

and time-wasting, but most of these failures were in the early stages of our experience with the capsule. The majority of the later studies were successful.

There are still doubts about the accuracy of the Heidelberg capsule, particularly in comparison with glass electrodes. But we have little doubt from our own experience that a capsule which calibrates and stabilizes satisfactorily at the start of its transmitting life-time will remain sensitive and accurate to within 0.5 of a pH unit until shortly before it ceases to transmit.

Because we have this confidence, we note with interest the considerable differences between the levels of intrajejunal pH which we have encountered and the much higher values which are usually given for the pH of jejunal juice (7.0 to 8.6, Magee, 1962; 6.5, Dawson, 1964). It seems that the intraluminal level of pH is different from that of isolated intestinal juice. This is not surprising considering the various factors which influence the pH *in vivo*. What is particularly intriguing is the possibility that in the fasting state, when intestinal secretion is basal and minimal, there is a flux of predominantly acid ions.

At least it seems clear that within the jejunum there are relatively constant patterns of pH response to certain stimuli. By studying these in greater number and detail we may learn something of the relation-

ship between intestinal pH and functional disorders of the small bowel.

SUMMARY

The pH of the proximal jejunum has been studied by radiotelemetry.

Data on the pH range in the fasting subject and in response to food, intravenous secretin, and infusions of dilute hydrochloric acid have been reported.

We wish to thank Professor McGirr for his interest in this work and for permission to study patients under his care.

REFERENCES

- Connell, A. M., and Waters, T. E. (1964). Assessment of gastric function by pH telemetering capsule. *Lancet*, **2**, 227-230.
- Dawson, A. M. (1964). Disturbances of intestinal absorption. In *Recent Advances in Medicine*, 14th ed., edited by D. N. Baron, N. Compston, and A. M. Dawson, p. 271. Churchill, London.
- Jacobson, B., and Mackay, R. S. (1957). A pH-endoradiosonde. *Lancet*, **1**, 1224.
- Magee, D. F. (1962). *Gastrointestinal Physiology*, p. 127. Thomas, Springfield, Illinois.
- Noller, H. G. (1960). Clinical applications of telemetering techniques. In *Proc. 3rd International Conference on Medical Electronics*, p. 111. London.
- (1962). Ergebnisse der Magenfunktionsermittlung mit der EndoradioKapsel, einem neuen Hilfsmittel der Magen-diagnostik. *Fortschr. Med.*, **80**, 351-355.