Continuous recording of pH in the duodenal bulb after food and alkali¹

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Only recently have we been satisfied with the data obtained from recording the pH of luminal contents within the duodenal bulb *in situ*. The improvement in technique consisted of concurrent recording of antral and duodenal transmucosal potential differences so that the site of the electrode could be determined without fluoroscopy (Archambault, Rovelstad, and Carlson, 1967). A logical application of this technique was the study of the effects of food and antacids on the acidity of duodenal bulb contents, since some investigators (Fordtran and Collyns, 1966) have found antacids to be more effective after a meal. The use of an indwelling glass electrode has many advantages. It avoids the possibility of the aspirating tubes being obstructed by food particles. Also, tube aspiration from the small volume of the duodenal bulb almost certainly attracts fluids from adjacent sites. The electrode *in situ* more likely records a pH that represents the fluid bathing the usual ulcer located in the duodenal bulb.

METHODS

The technique differed in two minor respects from that earlier described by us (Archambault *et al.*, 1967). The mercury bag was placed four inches from the electrode and was tied to only one side of the guard around the electrode to avoid food impaction. The original roller pump for the circulating KCl bridges was replaced by a Harvard pump operating two 25-ml syringes; this allowed a more accurate control of the amount of electrolyte pumped through the bridges.

A record of the pH of the resting stomach content was obtained before the electrode passed through the pylorus. After a satisfactory localizing potential difference was seen, a control pH was recorded from the duodenal bulb for 15 to 30 minutes. This period of control observation began about one hour after the subject first swallowed the recording leads. A meal of broiled, seasoned ground beef was then given. (The meat was blended to spare the subject the discomfort of excessive chewing.) A large supply of beef was frozen and identically prepared por-

tions were used on each occasion. A one-hour continuous record of pH was then made together with a recording of the potential differences for monitoring the position of the electrode. Then, 15 ml of antacid² followed by 30 ml of water was given and another one-hour record was made of the duodenal bulb pH. This particular antacid was selected because it had been used in our earlier study (Rovelstad and Maher, 1962) of antacid effects upon the pH of gastric contents.

Tests were carried out on 18 subjects. Six studies were discarded because records of potential differences indicated unsatisfactory placing of the glass electrode. This report is based on 10 studies on nine patients (five women and four men ranging in age from 28 to 70 years). Two patients had mildly active duodenal ulcers, one with a hiatal hernia. The remaining subjects were clinically free of stomach or duodenal disease and showed normal results on barium x-ray studies of the upper gastrointestinal tract. Ten recordings were made with the patient in the right lateral supine position and two with the patient in the sitting position. Recording after ingestion of food took place for a mean of 50 minutes; the mean duration of recording after antacid was 55 minutes. From 3 to 8 oz of the meal was well tolerated (mean 5.5 oz). One patient was studied for four hours on two occasions. All patients had a fasting gastric pH of less than 3.

RESULTS

Figure 1 depicts the mean pH response to food and antacid in the 12 studies. Data from individual subjects are summarized in the Table. The range of pH values was large at all observation times. There was no significant change in mean duodenal pH for the group as a whole for one hour after food. After antacid there was a minor decrease in pH for 45 minutes. For three subjects with fasting pH of less than 3, food initially caused an increase in pH and ingestion of antacid was followed by a progressive decrease in pH for 45 minutes. There was no increase in pH in either group during the first 15 to 30 minutes after antacid, the time when most persons with duodenal ulcer note relief of discomfort with ant-

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²A 7% suspension of magnesium and aluminium hydroxides (Maalox).

FIG. 1. Mean pH (15-minute periods) after food and antacid. Values on extreme left (time zero) indicate last 15 minutes of basal record. Solid line shows mean pH for entire group of 10 studies. Dotted line shows pH for three subjects whose fasting pH was less than 3.0. Vertical lines show range of observations and numbers on top show number of patients with records satisfactory for analysis.

acid. Of the six studies permitting appraisal of the pH response during the first 15 minutes after antacid, three showed an increase, two a decrease, and one no change in pH. The response is not apparently dependent on the pH level preceding administration of antacid. Ten studies permit a comparison between the first and the second 15-minute period after antacid; the pH decreased in six and increased in four.

Examination of mean pH values has limitations, as already discussed (Bircher, Mann, Carlson, Code, and Rovelstad, 1965). Therefore, in a recent study (Archambault *et al.*, 1967) we evaluated the effects of food and antacids on the basis of changes in pH around specific pH values. These specific values relate to 'proteolytic neutralization' levels and to the pH values thought to activate the duodenal mechanisms that inhibit gastric secretion.

Cumulative distribution and 'difference' curves permit such assessment of data and facilitate comparison of the widely variable pH curves during different periods (Bircher *et al.*, 1965). To expand the low end of the pH scale, where small changes in pH may reflect a large change in acid concentration,

FIG. 2. 'Difference' graph. Curves 1, 2, 3, and 4 (solid lines) show sequential 15-minute periods following ingestion of food. Curves 5, 6, 7, and 8 (broken lines) show the following sequential 15-minute periods after ingestion of 15 ml of antacid and 30 ml of water. In this subject, ingestion of food first increased and then decreased the pH of the bulb, especially in range pH > 3. Antacid reversed this, increasing the pH to above basal levels essentially only in the fourth 15-minute period after antacid (curve 8). The numbers in the boxes at the bottom indicate percentage of time the basal pH was equal to or less than the pH value indicated immediately above.

pH was plotted on a semi-logarithmic scale. The ordinate shows the difference, at each pH level, between the percentages of time the pH was at that level or lower during one test period and during the basal period (positive value if the postbasal period represents alkalinization and negative if acidification).

Such a 'difference' graph for one subject is shown

TABLE
MEAN pH VALUES FOR 15-MINUTE PERIODS

Test No.	Basal	After Food				After Antacid			
		1	2	3	4	5	6	7	8
1	4.90	6.30	5.70	3.80	2.90	3.10	3.50	3.70	4.40
2	3.20	4.40	3.50	—	—	2.20	2.50	—	—
3	4.80	4.50	3.85	—	—	2.40	3.40	—	—
4	6.00	3.50	5.00	5.60	5.40	5.60	6.50	6.60	6.60
5	6.45	6.20	6.00	6.70	6.20	5.40	5.45	5.50	—
6	2.00	1.80	4.40	3.60	5.40	5.40	2.70	3.20	—
7	4.90	4.90	5.40	5.20	5.90	5.20	5.90	5.60	5.80
8	6.40	6.40	5.15	—	—	3.00	2.60	2.40	—
9	6.45	6.45	3.70	3.20	—	3.50	2.85	2.70	2.40
10	2.40	2.40	3.80	3.20	3.00	4.20	4.10	3.10	4.65

in Figure 2. This shows that the bulb was more alkaline in the first two postcibal periods than in the basal state. Progressive acidification occurred thereafter. After the administration of antacid, the first three 15-minute periods continued to reflect acidification, at least at higher pH levels, as compared with the basal state. This acidification decreased with passage of time. During the fourth postantacid period, bulb contents were more alkaline than during the resting state, except for pH values greater than 5. In the pH range 1.8 to 2.5, all the postbasal periods represented relative alkalization, the fourth postcibal period the least alkaline, and the fourth postantacid period the most. The differences are small. One might justifiably emphasize that in this subject there has been appreciable alkalization between the fourth postcibal and the fourth postantacid period. However, such analysis of data from the other subjects revealed that sometimes there was no alkalization after antacids and sometimes further acidification.

Four general patterns emerged: (1) acidification after food, decreasing acidification after alkali but never alkalization above basal levels (three subjects); (2) alkalization after food with variable response after antacid (four subjects); (3) acidification after food, continuing acidification after antacid (two subjects); (4) equivocal pH change after food but alkalization after antacid (two subjects). In addition, one study was noteworthy in demonstrating, after food, alkalization in the low pH range and acidification in the middle and high pH ranges.

Duplicate studies in one subject (tests 1 and 8 in the Table) demonstrated postcibal acidification twice but alkalization on one occasion and acidification on the other after antacid. Thus, this more cumbersome method of data analysis results in conclusions very similar to those obtained when mean pH data were examined, namely, the effect of food and antacid on duodenal pH is quite variable.

DISCUSSION

Fordtran and Collyns (1966) have recently drawn attention to the need to study patients after feeding in order to assess the effects of antacids; most investigations have been done in the fasting state when gastric motility may be different. Therefore, in the present investigation, acid was stimulated by a meat meal and an antacid was given, as by them, one hour later. They found impressive neutralization of gastric contents by antacids given after a meal. These authors measured the pH of the aspirate and then converted it to hydrogen ion concentration on the basis of the activity coefficient of the hydrogen

ion at different pH levels in gastric juice as suggested by Moore and Scarlata (1965). Although it probably does not change their overall conclusions, it should be noted that the activity coefficients are based on average Na^+ and K^+ concentrations of gastric juice. It remains to be shown that this conversion is applicable to the problem at hand, the measurement of the hydrogen ion concentration where total ionic strength of the solution is dependent on the food and on the antacid's contributions of at least Mg^{++} , Na^+ , Al^{+++} , and Ca^{++} as well. Hydrogen ion activity, rather than concentration, may be of greater concern. This value is obtained by direct measurement using a glass electrode without further conversions. Thus, our findings are not entirely comparable to theirs even if we were studying antacid effects in the stomach rather than in the duodenal bulb. Despite these limitations, it is evident that Fordtran and Collyns are seeing much more prominent neutralization of intraluminal contents. An important feature of the study by Fordtran and Collyns (1966) was their use of each subject as a control in paired studies, a goal we have not yet attained with present instrumentation problems.

We did not find a consistent response in the duodenal bulb after food and antacid. The pH changes in the duodenal bulb did not correlate well with the common clinical impression that pain originating in duodenal ulcer improves soon after ingestion of antacid, as a consequence of neutralization of the bulb. The variable and seemingly unpredictable response of the duodenal bulb is emphasized in the one patient on whom it was possible to do the test on two separate occasions. On the first occasion, acidification was progressive in spite of the antacid, and four days later there was an increase in pH after antacid.

The pH in the normal and in the ulcerated duodenum has been reasonably well documented (Berk, Rehfuess, and Thomas, 1943; Rovelstad, Owen, and Magath, 1952; Rovelstad, 1956; Tomenius and Williams, 1960; Rovelstad and Maher, 1962; Andersson and Grossman, 1965; Bircher *et al*, 1965; Moore and Scarlata, 1965; Archambault *et al*, 1967). There is disagreement, however, on the nature of the rapid variation in pH in the duodenum (Archambault *et al*, 1967). Andersson and Grossman (1965) suggested that it might be due to unrecognized movements of the electrode toward or away from the pylorus. In the present investigation, this rapid variation in pH was frequently seen during periods of very stable recording of potential differences, suggesting that the electrode was relatively constantly sited in the duodenal bulb. It therefore seems unlikely that movement of the electrode was responsible for this pH fluctuation. It is more probable

that, in the ulcer-bearing part of the duodenum, there is in fact a very rapidly changing pH of the luminal contents, not only in the fasting state but also after eating and after ingestion of antacids. The rapid increase of pH of antral contents, which we occasionally observed as an incidental finding, was of special interest in view of earlier studies (Lawson, 1965) suggesting that bile reflux might be important in injuring antral mucosa.

SUMMARY

The pH of the human duodenal bulb area was studied by using a recording, guarded glass electrode *in situ* and flowing KCl bridges to monitor skin-gastric potential difference and thus identify the position of the glass electrode. The pH changes were observed after a meal of meat and then after a dose of aluminium magnesium hydroxide antacid. The response of the pH of the duodenal bulb contents was quite variable. Alkalinization after antacid was negligible. It seems important to assess antacid effects on duodenal bulb contents because this is the material bathing the usual duodenal ulcer.

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REFERENCES

- Andersson, S., and Grossman, M. I. (1965). Profile of pH, pressure, and potential difference at gastroduodenal junction in man. *Gastroenterology*, **49**, 364-371.
- Archambault, A. P., Rovelstad, R. A., and Carlson, H. C. (1967). In-situ pH of duodenal bulb contents in normal and duodenal ulcer subjects. *Ibid.*, **52**, 940-947.
- Berk, J. E., Rehfuess, M. E., and Thomas, J. E. (1943). In situ effects of antacids in duodenal ulcer. *Arch. intern. Med.*, **72**, 46-57.
- Bircher, J., Mann, C. V., Carlson, H. C., Code, C. F., and Rovelstad, R. A. (1965). Intraluminal and juxtamucosal duodenal pH. *Gastroenterology*, **48**, 472-477.
- Fordtran, J. S., and Collings, J. A. H. (1966). Antacid pharmacology in duodenal ulcer: effect of antacids on postcibal gastric acidity and peptic activity. *New Engl. J. Med.*, **274**, 921-927.
- Lawson, H. H. (1965). The effect of the duodenal contents on the gastric mucosa. *S. Afr. J. Surg.*, **3**, 79-92.
- Moore, E. W., and Scarlata, R. W. (1965). The determination of gastric acidity by the glass electrode. *Gastroenterology*, **49**, 178-188.
- Rovelstad, R. A. (1956). Continuously recorded in situ pH of gastric and duodenal contents in patients with and without duodenal ulcers. *Ibid.*, **31**, 530-537.
- , and Maher, F. T. (1962). Problems associated with assessment of the effects of diet antacids, and anticholinergic agents on gastric and duodenal acidity, as measured by the glass electrode *in situ*. *Ibid.*, **42**, 588-594.
- , Owen, C. A., Jr, and Magath, T. B. (1952). Factors influencing the continuous recording of in situ pH of gastric and duodenal contents. *Ibid.*, **20**, 609-624.
- Tomenius, J., and Williams, G. (1960). Continuously recorded pH of gastric and duodenal contents in situ with an evaluation of the efficacy of some antacids in vivo. *Acta med. scand.*, **166**, 25-34.