Gut, 1968, 9, 177-182

Effect of different foods on the acidity of the gastric contents in patients with duodenal ulcer

Part III: Effect of altering the proportions of protein and carbohydrate[1]

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The output of acid from an innervated canine gastric pouch is directly proportional to the nitrogen content of meals entering the stomach (Saint-Hilaire, Lavers, Kennedy, and Code, 1960). The buffering power of meals also depends on their protein content. High protein meals thus stimulate much acid secretion by the gastric mucosa and also buffer the acid secreted. The acidity of the gastric contents is therefore less than that of the pure gastric juice secreted by a pouch (Kahn and Yaure, 1924).

In patients with duodenal ulcer taking food the acidity of the gastric contents tends to be high for a greater proportion of the time than in normal subjects (James and Pickering, 1949). To shorten these periods of high acidity, opposing suggestions have been made about diets: a low protein–high carbohydrate diet has been recommended to reduce acid secretion (Dekkers, 1956) and a high protein diet has been advocated to buffer the acid secreted (Cleave, 1962). The experiments reported here were designed to test the effect on the acidity of the gastric contents of altering the ratio of protein to carbohydrate in equicaloric meals.

METHOD OF STUDY

The general methods of investigation and of analysis of the results were as described previously (Lennard-Jones and Babouris, 1965). Four experiments were performed and these will be described separately.

EXPERIMENT 1

PALATABLE EQUICALORIC DIETS STUDIED DURING WAKING HOURS Fourteen patients with duodenal ulcer were studied, eight given diets on two days of approximately 1,800 Cals and six given diets on two days of approximately 2,300 Cals. A high protein diet was given on one day and a low protein diet on another. The order in which the two diets were given was alternated from patient to patient. The composition of the diets is shown in Table I. It will be seen that breakfast and the evening meal were the largest meals, that corresponding meals on the two days were of equivalent caloric content but different in their content of protein and carbohydrate, that the fat content was the same on the two days, and that the diets were not unphysiological. Gastric samples were withdrawn half hourly between 8 a.m. and 10 p.m. inclusive on each of the two days of the test.

The distribution of samples in different pH ranges This is set out in Table II. It will be seen that the proportion of samples in the range pH 1·6-2·0 tended to be less, and that the proportion in the ranges less acid than pH 2·6 tended to be greater with the high than with the low protein diet.

The mean acidity This is shown in Figs. 1 and 2 at each half hour between 8 a.m. and 10 p.m. It will be seen that after each meal the acidity tended to fall to a lower level and to rise more slowly with the high than with the low protein diet. The differences are more obvious with the 2,300 Cal than with the 1,800 Cal diet but no conclusion can be drawn from this as different patients were studied in the two experiments.

Differences between pH values at corresponding times in the same patient The pH value of each sample obtained with the low protein diet has been subtracted from the pY value of the sample obtained from the same patient at the corresponding time with the high protein diet. The mean differences and significant departures from zero are shown in Table III. The acidity tended to be less with the high than with the low protein diet for one hour after lunch and for two and a half hours after supper with the 1,800 Cal diet; for one hour after breakfast, and one and a half hours after lunch, one hour after tea, and two and a half hours after supper with the 2,300 Cal diet.

[1]Part of this work was included in a thesis submitted by one of the authors (J.E.L.-J.) to the University of Cambridge for the degree of M.D.

[1]Full details of the results fcr every patient in experiments 1 and 2 have been published elsewhere (Lennard-Jones, 1964).

TABLE I

CALCULATED COMPOSITION OF THE HIGH PROTEIN AND HIGH CARBOHYDRATE DIETS USED IN EXPERIMENT 1

High Protein Diet	*Protein (g)*	*Carbohydrate (g)*	*Fat (g)*	*Cals*	*High Carbohydrate Diet*	*Protein (g)*	*Carbohydrate (g)*	*Fat (g)*	*Cals*
Breakfast Bacon and egg Bread and butter Milk					Fruit Bread, butter, and jam Tea, skimmed milk, and sugar				
	26 *(28·5)*	32 *(48)*	38 *(38)*	572 *(645)*		4 *(6·5)*	91 *(107)*	24 *(24)*	594 *(668)*
Lunch Stewed steak, potatoes and peas Egg custard					Pork chop, potatoes and cabbage, fruit, sugar				
	33 *(54)*	39 *(48)*	14·5 *(19)*	419 *(579)*		11 *(11)*	40 *(55)*	24 *(36)*	420 *(588)*
Tea Bread and butter Cheese Milk					Bread, butter, and honey Tea, skimmed milk, and sugar				
	9 *(14·5)*	22 *(38)*	15·5 *(20)*	264 *(390)*		3·5 *(45)*	44 *(63)*	12 *(12)*	292 *(376)*
Supper Haddock, peas, bread and butter Egg custard Milk					Bread, butter, and jam Fruit, sugar, and cream Tinned fruit juice				
	48 *(53·5)*	45 *(71)*	25 *(25)*	601 *(721)*		3 *(4·5)*	75 *(98)*	30 *(30)*	582 *(678)*
Totals									
Smaller diet	116	138	93	1,856		22	250	90	1,888
Larger diet	*(150)*	*(205)*	*(102)*	*(2,336)*		*(27)*	*(323)*	*(102)*	*(2,310)*

The figures for the larger of the diets are shown in italics. In this, and subsequent analyses of diets, the calculated values are derived from the published figures of McCance and Widdowson (1960).

TABLE II

DISTRIBUTION OF GASTRIC SAMPLES IN DIFFERENT pH RANGES WITH HIGH PROTEIN AND HIGH CARBOHYDRATE DIETS OF APPROXIMATELY 1,800 AND 2,300 CALS

Diet				*No. of Samples in Different pH Ranges*						
Protein (g)	*Carbohydrate (g)*	*Fat (g)*	*Cals*	*1·5*	*1·6—2*	*2·1—2·5*	*2·6—3*	*3·1—3·5*	*>3·5*	*Total*
116	138	93	1,856	59	71	28	21	15	29	223
22	250	90	1,888	58	101	29	14	9	10	221
150	205	102	2,336	48	29	23	11	18	42	171
27	323	102	2,310	47	69	22	9	11	10	168

TABLE III

MEAN DIFFERENCES BETWEEN pH OF SAMPLES DURING HIGH PROTEIN DIET AND pH OF SAMPLE TAKEN FROM THE SAME PATIENT AT THE CORRESPONDING TIME WITH HIGH CARBOHYDRATE DIET[1]

		Time											
		9.00 a.m	*9.30*	*12.30 p.m.*	*1.00*	*2.00*	*4.00*	*4.30*	*6.30*	*7.00*	*7.30*	*8.00*	*8.30*
1,800 Cal	Mean difference			+1·22	+1·00				+1·87	+1·08		+0·44	+0·56
	(SE)			(0·23)	(0·32)				(0·31)	(0·29)		(0·16)	(0·21)
	Significance			<0·01	<0·02				<0·001	<0·01		<0·05	< 0·05
2,300 Cal	Mean difference	+1·50	+1·03		+1·41	+1·03	+0·93	+0·77	+1·89	+2·16	+1·49	+1·26	+1·04
	(SE)	(0·46)	(0·24)		(0·52)	(0·38)	(0·31)	(0·28)	(0·63)	(0·33)	(0·21)	(0·27)	(0·25)
	Significance	<0·05	<0·01		<0·05	<0·05	<0·05	<0·05	<0·05	<0·01	<0·001	<0·01	<0·01

[1]Only those mean differences which depart significantly from zero are shown.

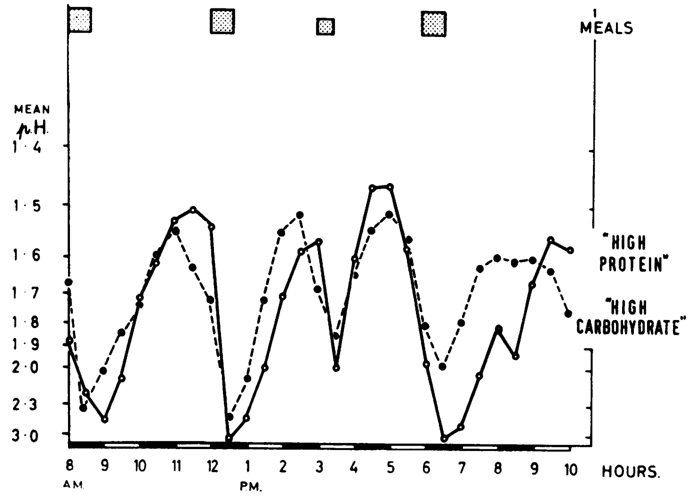

FIG. 1.

FIG. 1. *Mean acidity of the gastric contents in eight patients with duodenal ulcer taking high protein and high carbohydrate diets of approximately 1,800 calories.*

FIG. 2. *Mean acidity of the gastric contents in six patients with duodenal ulcer taking high protein and high carbohydrate diets of approximately 2,300 calories.*

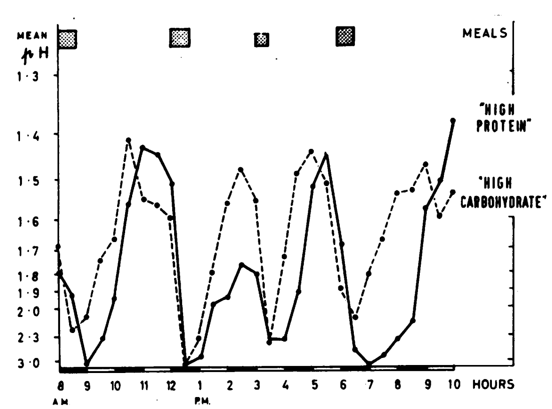

FIG. 2.

EXPERIMENT 2

EQUICALORIC MEALS OF THE SAME CONSISTENCY BUT WITH DIFFERENT PROPORTIONS OF PROTEIN AND CARBOHYDRATE In the previous experiments it proved impossible to design equicaloric diets, with the designed proportions of protein and carbohydrate, which were palatable, physiological and yet had the same consistency. The low protein diet tended to have a more liquid consistency than the high protein diet because it contained more sugar and soft fruits. The following experiment was therefore designed to examine the effect of altering the ratio of protein to carbohydrate in single meals equal not only in fat content and caloric equivalent but also in bulk and consistency.

Six patients with duodenal ulcer were studied. On the two days of the test each patient had the same breakfast and mid-morning drink. Control gastric samples were obtained at 11.45 a.m. and 12 midday. A test lunch was then given and seven further samples were obtained at half hourly intervals after the start of the meal. The composition of the two test meals used is summarized in Table IV. It will be seen that the fat content, caloric equivalent, weight of solids, and amount of liquid were approximately equal in the two meals, but that the ratio of protein to carbohydrate was different. The meal with the most protein consisted mainly of fish, bread, butter, and milk. The meal with less protein contained more fruit than is usual in an English diet.

The mean acidity This, at various times after the two meals, is set out in Figure 3. The acidity fell to a lower level and rose more slowly after the meal containing much protein than after the meal containing less protein. Mean differences between the samples at corresponding times departed significantly from zero, the acidity being lower with the meal containing most protein, at 30 ($P < 0.02$), 60 ($P < 0.01$), and 90 ($P < 0.05$) minutes after the start of the meal.

EXPERIMENT 3

REFINED AND UNREFINED MAIZE It has been suggested that the consumption of highly refined cereals, from which protein has been removed, is an aetiological factor in the development of peptic ulcer (Cleave, 1962). The effect of unrefined maize meal (10 g protein/100 g) and of maize cornflour (0·5 g protein/100 g) on the acidity of the gastric contents has therefore been studied.

After standard meals earlier in the day, six patients with duodenal ulcer took at 3 p.m. on two different days

TABLE IV

COMPOSITION OF TEST MEALS USED IN EXPERIMENT 2[1]

Diet	Food	Liquid (ml)	Solid (g)	Protein (g)	Carbohydrate (g)	Fat (g)	Cals
High protein	Haddock, peas, bread and butter, egg custard, milk	400	310	53·5	71	25	723
High carbohydrate	Orange juice, bread, butter, jam, raw apple, tea, milk, sugar	400	315	7·5	118	26	736

[1]The weight of solids, volume of liquids, fat content, and caloric equivalent were similar; the proportions of protein and carbohydrate were varied.

either 50 g of steamed maize meal or 50 g of steamed cornflour, both rendered palatable by the addition of constant amounts of light cream and fruit juice. Gastric samples were obtained 15 minutes before, at the start of the meal, and at 30-minute intervals for three hours.

The mean acidity of the gastric samples after the two meals is shown in Figure 4. The acidity fell to a lower level and rose more slowly after the unrefined maize meal than after cornflour. The mean differences between corresponding samples departed significantly from zero, the acidity being less with the unrefined than with the refined cereal, 30 minutes after the meal ($P < 0{\cdot}01$).

EXPERIMENT 4

BREAD OF DIFFERENT PROTEIN CONTENT The results obtained with maize are not relevant to countries in which the staple cereal is wheat. Two types of bread were therefore studied, white bread with a 70% extraction rate containing 8 g of protein per 100 g, and brown bread, Hovis, of 70% extraction rate with 20% added wheat germ giving a total protein content of 9 g per 100 g.

After an overnight fast, eight subjects with duodenal ulcer took a test breakfast consisting of 120 g of crustless white or brown bread made into small sandwiches with 8 g of butter and 15 g of honey, and 30 ml of Sunfresh orange squash diluted to 200 ml. Samples were withdrawn 15 minutes before, at the start of the meal, and then at half-hour intervals for three hours.

The mean acidity of the samples at different times after the meal is shown in Figure 5. The acidity

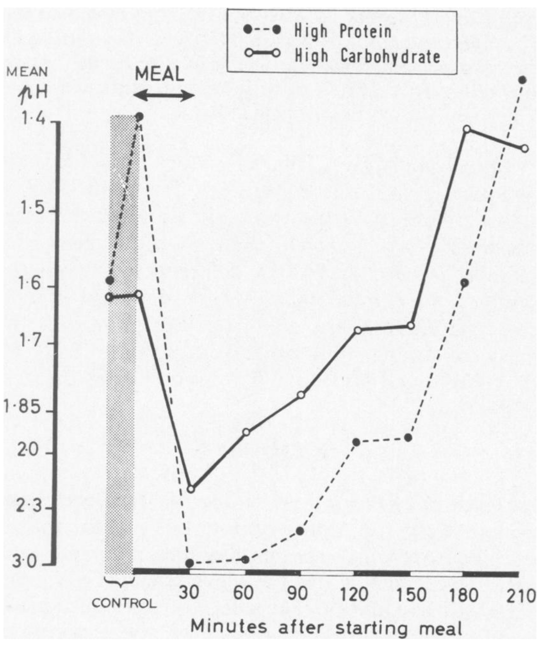

FIG. 3. *Mean acidity of the gastric contents in six patients with duodenal ulcer given test meals of the same bulk and consistency but varying in the proportions of protein and carbohydrate.*

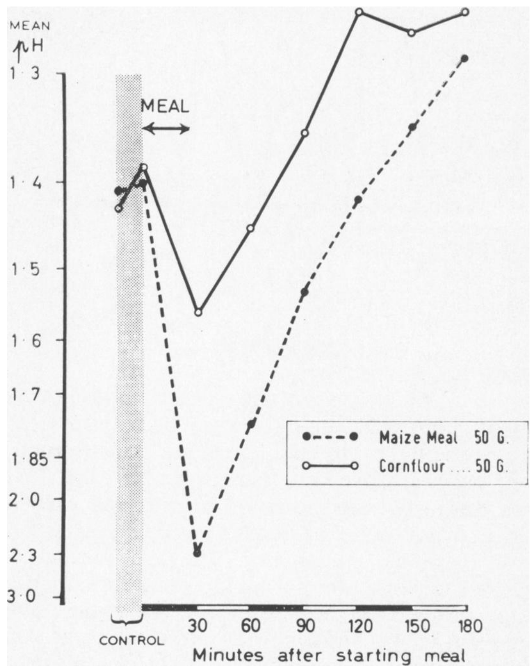

FIG. 4. *Mean acidity of the gastric contents in six patients with duodenal ulcer after meals of maize and cornflour.*

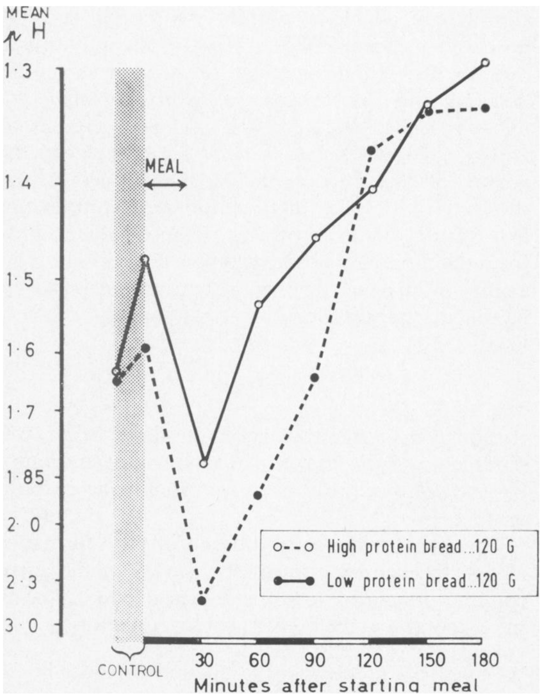

FIG. 5. *Mean acidity of gastric contents in eight patients with duodenal ulcer after taking bread of differing protein content.*

tended to fall to a lower value and to rise more slowly after the brown bread which contained slightly more protein than the white bread. Mean differences between corresponding samples departed significantly from zero, the acidity being less after the brown bread, 30 minutes after the start of the meal ($P < 0{\cdot}01$).

DISCUSSION

From the work of Schüle (1895) onwards, it has been known that the acidity of the gastric contents is reduced for a longer time after foods containing a high proportion of protein than after foods containing little protein. Besides buffering acid, protein stimulates acid secretion (Saint-Hilaire *et al.*, 1960) and Woldman, Fishman, Knowlton, Rousuck, and Stoner (1948) concluded from their studies in man that a high peak acidity followed the initial buffering of gastric acid when a protein hydrolysate was given. Depending on whether the buffering or stimulant effects of protein are considered the more important, some authors have regarded a high and others a low protein content of the diet as important in the aetiology and treatment of duodenal ulcer. No previous investigators have studied the effect on the acidity of the gastric contents of altering the ratio of protein to carbohydrate in equicaloric diets containing a constant amount of fat.

The results of the first experiment, in which two such diets were given, show that the acidity of the gastric contents falls to a lower level and rises more slowly after a meal with a high ratio, than after a meal with a low ratio, of protein to carbohydrate. Breakfast and supper differed little in caloric equivalent but supper contained more protein. A comparison between the gastric acidities after these two meals shows that the acidity rose more slowly after supper than after breakfast suggesting that the duration of low acidity after a meal depends on the quantity of protein eaten.

The conclusion of Woldman *et al.* (1948) that the initial buffering of gastric acid by protein is followed by a high peak acidity was based partly on a comparison between the fasting value and the acidity 45 minutes or more after a drink containing 25 g of protein hydrolysate in water. In the present observations, the peak acidity three to four hours after breakfast was apparently greater than the fasting value. However, the peak acidity at this time was not obviously related to the protein content of the preceding meal. Woldman and his colleagues also observed higher and higher acidities after successive drinks of protein hydrolysate. In the present study the peak acidities before lunch, tea, and supper were similar. The acidity at these times was not consistently higher with the diets containing most protein and differences between the peak acidities observed can be attributed to the error of the method.

Malhotra (1964) suggests that the saliva secreted during mastication buffers gastric acid and that foods which are swallowed with little or no mastication become mixed with little saliva and therefore buffer less acid. The consistency of a meal may thus affect the subsequent acidity of the gastric contents. In the first experiment the diets containing the most carbohydrate, because of their high sugar content, tended to have a more liquid consistency than the diets containing most protein. In the second experiment, this factor was taken into account and meals equal not only in caloric equivalent and fat content, but also in solid and liquid constituents, were tested. As in the first experiment, the acidity of the gastric contents fell to a lower level and rose more slowly after the meal containing more protein than after the meal containing less protein, suggesting that the protein content of the meal, as well as the consistency, affects the subsequent acidity of the gastric contents.

Cleave (1962) has advanced evidence, derived from surveys in different parts of the world and in unusual circumstances, such as prisoner-of-war camps, that a high incidence of peptic ulcer is associated with a high consumption of refined cereals. He attributes this association to removal of protein during milling of the cereals so that these foods no longer adequately buffer gastric acid. Analyses of the protein content of refined and unrefined cereals (Table V) show that in most instances very little protein is removed by milling. Maize was chosen for study in our third experiment because with this cereal most of the protein is removed during the production of cornflour. The results of the experiment show that the acidity of the

TABLE V

PROTEIN AND CARBOHYDRATE CONTENT OF REFINED AND UNREFINED CEREALS

Cereal	*Protein (g/100 g)*	*Carbohydrate (g/100 g)*
English flour[1] 100%	8·9	73·4
English flour 70%	7·9	81·9
Wholemeal bread[1]	8·2	47·1
White bread	8·0	51·7
Hovis bread	9·0	47·6
English rye[1] 100%	8·0	75·9
English rye 60%	5·6	85·8
Maize, wholemeal[2] 100%	10·0	71
Maize, refined 60%	8·0	77
Maize cornflour	0·5	87
Rice, lightly milled[2]	8·0	77
Rice, polished (white)	7·0	80
Millet, whole grains[2]	11·0	69
Millet, meal	9·0	76

[1]Data from McCance and Widdowson (1960)
[2]Data from Platt (1962)

gastric contents falls to a lower level and rises more slowly after taking unrefined maize than after taking cornflour. Since the staple cereal of western countries is wheat, our fourth experiment concerned two types of bread. There is little difference in protein content between white and wholemeal bread. White bread was therefore compared with brown bread made of flour of a similar extraction rate to which had been added a supplement of wheat germ. The results of this experiment showed that the acidity of the gastric contents was less and rose a little more slowly after the brown bread, which contained slightly more protein than the white bread.

The experiments described support the hypothesis that a diet rich in protein reduces the acidity of the gastric contents and suggest that the duration of high acidity in the stomach is less during waking hours when a high rather than low protein diet is taken. The observations of Gillespie (1959), Woodward (1960), and others suggest that the stomach continues to secrete acid until the acidity of the antral contents rises to a critical level of about pH 1·5 when gastric secretion is inhibited. The apparent stimulatory effect of protein on gastric secretion observed by Saint-Hilaire *et al.* (1960) may thus be due to the buffering effect of protein which, by delaying the rise in gastric acidity, prolongs the duration of gastric secretion and so increases the amount of acid secreted in response to the meal. The acidity of the chyme entering the duodenum may thus vary little with diets of different composition. For this reason, if no other, it is impossible to judge from the present evidence whether the periods of low acidity after meals rich in protein are an important factor in the aetiology or treatment of duodenal ulcer.

SUMMARY

Patients with uncomplicated duodenal ulcer were given equicaloric meals with a constant amount of fat but different proportions of protein and carbohydrate.

The form of the meal differed in the four experiments. In each experiment the acidity of the gastric contents remained low for a longer time after the meal containing the higher protein content.

We thank the physicians who allowed us to study their patients, Dr. E. N, Rowlands for his help and encouragement, Miss G. M. Cave and her staff for preparing the diets used at University College Hospital, Mrs. I. M. Prentice and the Department of Medical Illustration at the Central Middlesex Hospital for the diagrams.

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