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The Physiology of Gastric Digestion

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by
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PREFACE

A book written by a clinician at the invitation of physiologists must attempt to bring followers of the two disciplines to terms. The different experimental animals with which they mainly concern themselves and the different classes of experiment which it is consequently in their power to perform have led to divergences of view, examples of which will be found in the following pages. Frank conflict apart, unequal emphasis is placed on some features of gastric physiology by clinicians and by physiologists, and I have made a special attempt to explore those corners of the field which writers on physiology tend to pass by.

Possibly because it is at an earlier stage of development, clinical science is mainly concerned with circumscribed unambiguous questions which can be visualized and comprehended, and which can be answered experimentally with yes or no. Physiology, on the other hand, dealing so often with a submicroscopic reality, is compelled to formulate its hypotheses in more abstract terms, and is correspondingly more free to modify or abandon its conclusions. True and false are adjectives which have more meaning in the ward than in the laboratory. Consequently, in discussing problems of various classes, one is now trying to weigh proof against disproof, now attempting a synthesis of apparent incompatibles: some readers may therefore find passages which are more in the nature of a debate than they would welcome, while others will elsewhere have difficulty in discerning a conclusion. This book is written in the belief that truth is of different categories and degrees of abstraction.

It would not have been written at all without the assistance, for which I am most grateful, of the Editorial Board of the Monographs of the Physiological Society, especially Dr. W. Feldberg and Dr. L. E. Bayliss ; of Miss E. Lumley Jones, librarian to the Welsh National School of Medicine and of her staff; and of Professor Harold Scarborough.

A.H.J.

CONTENTS

CHAPTER I

THE NATURE OF THE GASTRIC CONTENTS IN MAN

The small intestine is the *raison d'être* of the alimentary tract; in it food can be completely digested and its lining is adapted to the closely related function of absorption. It differs from the specialized viscera which lead to and from it, that is from the stomach and colon, in being indispensable: in common with other such organs, for example the kidneys or the lungs, its size makes it more than adequate for its purpose; there is a large reserve of intestinal function.

The large absorptive surface of the small intestine constitutes something of a hostage to fortune; its necessarily permeable covering and large blood supply make it fragile and delicate, and a generous portal through which noxious substances can enter the body and valuable fluid and mineral leave it. Access, unimpeded by protective integument, to such a fragile tissue from the outside environment is paralleled only in the cases of the lungs and the organs of special sense. As these have their defensive mechanisms, so does the intestine in the form of the stomach whose position and structure enable it to receive, edit, and if necessary reject, ingested material which would otherwise reach and possibly injure the intestine.

That the stomach could have such a function is apparent from its anatomy. How much, or with what degree of efficiency it fulfils it is a matter for experimental analysis, directed to determining the nature of the effluent from the stomach, and the degree to which ingested food has undergone alteration. The characteristics of food and drink which deserve consideration in this context are their quantity, physical nature, chemical nature, osmotic strength, temperature and bacterial content. An excess or departure from the bland ideal in any of these respects might damage the intestinal mucosa. It is the purpose of the present chapter to review what is known of the state of the stomach contents, and what changes, under the above-enumerated headings, occur during 'gastric digestion'.

Other possible functions of the stomach are enzymic digestion and absorption. The extent of digestion, if any, will be revealed by chemical analysis of stomach contents, and such evidence as there is on this point will also be considered here. Gastric absorption, being slight, can only be measured by special experiments; the results of these are reviewed by Karel (1948). While the fact of such absorption is of interest, the evidence seems to be that the amount of it is not such as to make a significant contribution to the absorption of a meal. Apart from a consideration of the possibility that acid is absorbed, the question of gastric absorption will be ignored in this book.

Solid food in the stomach

It is not surprising that relatively few observations have been made on the gastric contents after solid food has been eaten: liquids can be aspirated easily and liquid test substances are more convenient and reproducible. To investigate the state of affairs in the stomach after eating ordinary food, a narrow tube such as the Ryle or Rehfuss tube is of limited value: the extensive studies of Rehfuss, Hawk and colleagues (e.g. Fishback *et al.* 1919) were made by this method, and gave the acidity of whatever fluid could be aspirated, and the time which it took for the material of the food to disappear from the aspirate. Solid food cannot of course be aspirated through such a tube. In the studies of James and Pickering (1949) on the acidity of gastric samples during the consumption of ordinary food it was sometimes surprising how thick was the material which would come up a Ryle tube, the sample occasionally being of a consistency such that it could barely be poured; but usually one can only aspirate material from the liquid phase of what must be a mixture of liquid and solid.

The evidence from direct observations upon the stomach contents of animals and from radiological observations in man is that food swallowed in a semi-solid state remains in that state for a surprisingly long time, and that it is only very gradually penetrated from without by gastric secretion. Cannon (1898) killed cats and examined the state of their stomach contents at various intervals after eating. He drew attention to the different state of the contents of the two main parts of the stomach. 'The food in the fundus of a cat has the same mushy appearance when examined after gastric peristalsis had been active for an hour and half that it had when ingested. The contents of the antrum, on the other hand, have the consistency of thick soup.' He fed cats with 5 grams of bread with bismuth, then 5 grams without bismuth, and finally 5 grams again with bismuth. By means of X-rays, even in their then primitive state, he was able to see that the two dark layers were 'arranged along the curvatures with a light layer between'. This stratification disappeared in the pyloric part 10 minutes after peristalsis commenced, but 80 minutes later the layers could still be seen in the cardiac region.

A further experiment of Cannon's shows how long it takes for acid to penetrate the food mass in the stomach. He gave a cat, previously starved for 15 hours, a meal of bread made alkaline with sodium carbonate. An hour and a half after the cat had finished eating it was killed. Fluid removed from the periphery of the fundal contents was acid, but food aspirated from a depth of $2\frac{1}{2}$ cm. into the mass was still alkaline: the contents of the pyloric antrum, on the other hand, were liquid and acid from whatever depth they were obtained. Similar results were obtained in a dog killed $1\frac{3}{4}$ hours after eating.

Gianturco (1934), using cats, came to similar conclusions. His method was to feed cats with lumps of meat coated with barium sulphate and take radiographs at intervals during digestion. His pictures show the outline of the lumps in the stomach. Within 10 minutes the outlines in the pyloric antrum faded, and the whole region became diffusely opaque. The interpretation that the food had been liquefied in this area was confirmed in a cat killed during this phase. After one hour, liquefaction had spread into the body of the stomach, and after two hours, lumps could only be seen in the centre of the fundus. The contents of the stomach appeared to become liquefied from outside inwards.

Nielsen and Christiansen (1932) made similar investigations in the human stomach. Their general method was to give their subjects a meal, successive parts of which either contained or did not contain a contrast medium. The food was either fried balls of minced meat, or oatmeal porridge. The subjects were students who attended lectures in the intervals of being radiographed. Their published photographs, a tracing from one of which is shown in Fig. 1, show clearly that the successive portions remain distinct or nearly so throughout their sojourn in the stomach. Usually the successive layers were disposed horizontally but sometimes the lines of demarcation were oblique (as in Fig. 1) or almost vertical. As the stomach emptied, the lowermost part of the meal, usually that ingested first, left the pyloric antrum, and the contents of the

10 min. 35 min. 65 min.

FIG. 1. Tracing from radiographs taken at the times stated after a normal subject had eaten 200 grams of fried meat ball without contrast medium, 50 grams mixed with Neobar, and then 100 grams without. Tracing from Nielsen and Christiansen (1932)

fundus narrowed and tended to move towards the pylorus, the boundaries between the layers becoming distorted in the process but remaining distinct. In one experiment, a mass of meat impregnated with contrast medium still occupied the gastric fundus 126 minutes after the end of the meal. These experiments make it unlikely that a semi-solid meal is mixed and liquefied in one piece, or that the proximal half of the stomach is anything other than a receptive bag.

Gianturco, and Nielsen and Christiansen, also investigated the behaviour of radio-opaque liquid drunk while the stomach contained solid food. Their experiences, with cat and man respectively, were similar. The drink did not mix with the food, but by-passed it, and left the stomach within a few minutes. In one of Nielsen and Christiansen's experiments it was at least10 minutes before the fluid could find a way round the solid mass of food, so completely was the lumen of the stomach blocked. Usually the fluid chose no particular route past the obstruction, but trickled down, often in such a way as to surround momentarily the mass of food. Only occasionally, and apparently by chance, did fluid pass down by the lesser curve, along the traditional 'magenstrasse'. In fact it is to be doubted, in the light of these experiments, whether the 'magenstrasse' carries any traffic at all, or is any more than a hypothetical pathway suggested by the appearance of rugal anatomy.

Rate of emptying of solid food

The emptying of solid food is less easily described in quantitative terms than is that of fluid; the time of disappearance of the last part of the meal, determined either by sampling or by the use of contrast medium, is all that has been measured.

Maile and Scott (1935) investigated the emptying of ordinary foods by mixing them with a small amount of barium emulsion. Their series was small, comprising three doctors, their wives, and a medical student, whose ages varied from 18 to 45. Breakfast of toast, butter, marmalade and tea, eaten at 9 a.m., was gone from the stomach by 1.10 p.m. Lunch, consisting of rabbit in casserole, potatoes and greens, biscuits, butter and cream cheese, and water, eaten between 1.30 and 2 p.m., was by no means emptied when tea, with scone and butter, bread and butter and sponge cake was eaten at 4.35 p.m. By 7.15 p.m. the stomach was once again empty. Dinner at 7.30–8 p.m. was composed of sherry, fatty soup, chicken, fried potatoes, toast and butter and coffee. At 10 p.m. the stomach was described as full, but was empty at 11.40 p.m. in spite of a snack of shortbread and tea at 10 p.m. These authors say that an ordinary meal takes $3\frac{1}{2}$–$4\frac{1}{2}$ hours to leave the stomach, so that the main meals of the day find a more or less empty stomach to receive them. They also record the conclusion that the emptying time of a meal depends less upon its size than upon its content of fat. Annegers and Ivy (1947) gave normal human subjects mixed meals of chicken, peas, bread and fruit, but having different fat contents, not exceeding quantities usually found in mixed meals. They gave a small amount of barium 4 hours later, and measured the area of the stomach so revealed; the area was proportional to the amount of fat in the meal. Van Liere and Sleeth (1938) fed dogs with hamburger, bread and milk: trebling the size of the meal doubled the time required for emptying, judged radiologically.

The physical state of food appears to be important in regulating emptying, sometimes more important than its chemical nature. Gianturco (1934), for example, found that in cats meat in large pieces left the stomach more slowly than did mashed potato, but ground liver left more quickly. Wilson, Dickson and Singleton (1929) watched the progress of food through the human stomach by means of X-rays. Solid food formed a 'ball' in the fundus, which gradually developed a pointed salient spreading into the antrum. They timed the interval between the eating of the food and the time of the first passage of a part of it into the duodenum. Usually this happened within 10 minutes, but when bran was added to the food, it was delayed, sometimes for as long as an hour and a half. Apart from food containing bran emptying was complete with all foods in $4\frac{1}{2}$ hours, and often in 3 hours.

The taking of water with meals seems to have little effect on the progress of solid food: as has already been noted, drink taken with food does not mix with the mass of its solid components, but finds its way past it by one route or another, to reach the pylorus and duodenum before it. Van Liere and Northup (1944) found in human subjects that water taken even with so fluid a substance as porridge did not affect the emptying time.

The effects on gastric emptying of the circumstances in which food is eaten may be large: they are, however, difficult to demonstrate. Evidence is quoted in Chapter V to show that the way in which food is served makes a lot of difference to the 'appetite secretion' evoked; the same may be true of emptying, but the author knows of no evidence that this is so. One would expect, also, from what has been said of the more rapid emptying of food when it is finely divided, that the duration of its stay in the stomach depends a good deal on the thoroughness with which it has been chewed. Emotional disturbances are particularly hard to assess. It is well known that unpleasant emotion can inhibit gastric movements and delay the emptying of a test meal. Wolf and Wolff's (1947) prolonged study of a fistulous human subject constitutes a bold attempt to take the matter a stage further. Their particular contribution was to show that emotion of different kinds may have directly opposite effects upon the stomach. Their work in connexion with secretion is discussed later (Chapter V).

During one set of experiments, the subject ate a specific breakfast, which included 1 pint of milk and a lot of butter, at 6–6.30 a.m. each day. The gastric contents were inspected through the fistula at various times, and it was found that under ordinary circumstances, that is, when the subject was untroubled and contented, this meal took about 6 hours to leave the stomach completely. Without butter or milk the time was $4\frac{3}{4}$ hours and with extra fat about 10 per cent of the meal remained at 6 hours. For three weeks, while the subject was taking the average breakfast, his equanimity was disturbed by financial troubles which made him both anxious and resentful. Throughout the period his stomach was empty in 4–5 hours. On the other hand, on a single occasion when he had a morning interview of which he was fearful, 20 per cent of the meal remained in the stomach after $6\frac{1}{2}$ hours.

The significance of this observation is not easily appreciated by anyone unfamiliar with the day-to-day variation in the subject's emotional state. Also, the degree of variation in 'emptying time' is not expressed quantitatively; when the gastric emptying of fluid is