each step has, to my mind, confirmed and expanded the conclusions I reached long years ago regarding the essential nature of the arteriosclerotic progress. I appreciate too highly the originality of Dr. Klotz to claim more than having been fortunate in suggesting to him that line of inquiry into the nature of calcification which he carried out with so much distinction and of which much of his later work is, as it were, a natural evolution. I should be glad to regard this address, and to have this address regarded, essentially as a vehicle for bringing forward in a connected manner the observations of my colleague and my interpretation of them, which must not necessarily be thought to be his interpretation.

SOME CONDITIONS AFFECTING THE DISCHARGE OF FOOD FROM THE STOMACH.

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and

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The purpose of this investigation was to determine as accurately as possible, under otherwise normal conditions, the influence of some of the commoner physical, chemical, and biological factors on the movements of the stomach and on the rate at which it discharges food into the intestine. The method employed was that used by one of us in studying the passage of different foodstuffs from the stomach.[1] The food used, except when otherwise specified, was 25 c.c. of mashed potato, with which was mixed 5 grams of subnitrate of bismuth. The consistency, which depends upon the amount of water added, was always as nearly uniform as could be judged by the eye and by manipulation. It will appear, however, from observations described below, that within the limits involved variations of consistency have no appreciable effect on the rate of gastric discharge of this food. Full-grown normal cats, deprived of food for twenty-four hours previous to the experiment, served for observation. In all the experiments, except those with fluid food, the animals were placed on the holder and fed from a spoon with no special difficulty. At regular intervals after feeding, observations were made by means of a fluorescent screen illuminated by the x-rays; and the dark shadows made by the food were traced in outline on transparent paper laid over the screen. The aggregate

[1] Cannon, Amer. Jour. Med. Phys., 1904, xii, 387.

length of these shadows measured the relative amount of food in the intestine at the different times of observation.

The method has been demonstrated to be above serious criticism.[2] During the first two hours, when the aggregate length of the food-masses in the intestine is most significant as an indication of the rate of gastric discharge, the intestinal content is usually not great, and can therefore be traced with only slight liability to error.

In establishing the normal rate of discharge as a basis for comparisons, the possibility of subjective differences, the personal equation, is involved. That Magnus[3] has recently used the method above described, with no essential variations from the original results, indicates that the personal equation need not be great. In order to estimate the extent of a possible deviation in our work, however, the original observations on mashed potato were repeated by one of us (Hedblom). The two tables which follow show a close agreement in the results independently obtained.

Hours after feeding	½	1	2	3	4
Aggregate length, in cm., of food masses in small intestine (Cannon)	9	30	43.5	28	22
	10	39	53.5	28.5	26
	9.5	22	36	36.5	30
	9	30.5	39	8	7
Average (4 cases)	9.5	30.5	43	25	21

Hours after feeding	½	1	2	3	4
Aggregate length, in cm., of food masses in small intestine (Hedblom)	10	32	42	31	31
	7	24	43	34	26
	11	29	43	33	23
	13	27	38	33	30
Average (4 cases)	10	28	41.5	32.5	27.5

After thus determining that a resonably close agreement existed between the results secured by the use of the method by different persons, we undertook a study of the effects on the rate of gastric discharge, of variations in the consistency of the food, the presence of gas in the stomach, extremes of temperature, different degrees of acidity, massage, irritation of the intestines, and fatigue.

THE INFLUENCE OF CONSISTENCY. A number of investigators have studied the effect of varying the water content of the food, as well as the rate of discharge of various liquids. In some of these researches animals with duodenal fistulas were used; in others the stomach tube was relied upon to determine the rate of discharge. Moritz,[4] who used the fistula method, found that water begins to leave the dog's stomach immediately after being swallowed, and that the stomach is almost emptied in fifteen to thirty minutes. In one case milk was discharged with similar rapidity; in another case, when the milk coagulated, the stomach was not emptied for

[2] Cannon, loc. cit., p. 391.

[3] Archiv f. die ges. Phys., 1908, cxxii, 210.

[4] Ztschr. f. Biol., 1901, xlii, 572.

one and a half hours. These results Moritz confirmed on man. He states that water leaves the stomach of man as quickly as it leaves the stomach of the lower animals; but that beer, milk, bouillon, and thin soup remain longer than water. Even with the least fluid of the substances he used—a thick soup—the stomach was practically empty in an hour. These observations, that liquids leave the stomach rapidly, are confirmed by the work of Hirsch,[5] Penzoldt,[6] Schüle,[7] and Roux and Balthazard.[8] These studies, however, are concerned almost entirely with liquids and not with the discharge of a certain food in various consistencies. To obtain information regarding the effects of varying consistency and other mechanical factors on the gastric discharge, observations were made on more or less viscous samples of potato, on hard particles mixed with the food, and on coarse graham bread.

1. *The Influence of Variations in the Viscosity of the Food.*—For this study potato was used. It was baked in order to drive off most of the water. Two series of observations were made. In the first series no water was added; the potato when mixed with bismuth subnitrate and ready for feeding was very thick and doughy. In the second series water was added until the mixture was of the consistency of thin gruel. The volume fed in all cases was 25 c.c. The results with these extremes of consistency should be compared with the results when potato of the standard consistency (intermediate between the extremes) is fed. The following were the figures obtained.

Potato, thick doughy consistency.

Hours after feeding	½	1	2
Aggregate length, in cm., of food masses in small intestine	5	11	28
	16	28	49
	17	28	41
	13	40	54
	5	17	35
Average (5 cases)	11	25	41.5

Potato, thin gruelly consistency.

Hours after feeding	½	1	2
Aggregate length, in cm., of food masses in small intestine	14	20	35
	9	17	31
	15	22	40
	17	20	40
	18	37	42
Average (5 cases)	14.5	23	37.5

As the curves in Fig. 1 show graphically, the rates of discharge of the same kind of food with fairly widely varying consistencies are nearly the same. Indeed, the rates of discharge do not differ among themselves enough to permit any noteworthy significance to be attributed to the differences in consistency.

[5] Centralbl. f. klin. Med., 1893, xiv, 75.
[6] Deut. Archiv f. klin. Med., 1893. li, 567.
[7] Ztschr. f. klin. Med., 1896, xxix, 49.
[8] Arch. de phys., 1898, xxx, 90.

Further evidence that consistency alone is not a prominent factor in determining the rate of gastric discharge is furnished by Moritz,[9] who observed wide differences in this rate when various fluids of practically the same consistency were given. Thus, water passed from the stomach much faster than beer, and considerably faster than bouillon.[10] On the whole, the conclusion seems warranted that while liquids leave the stomach very rapidly, more or less dilution of a food predominantly carbohydrate has but slight effect in modifying the rate of gastric discharge.

Protein food leaves the stomach more slowly than carbohydrate. The explanation for this phenomenon is that the union of protein with the acid of the gastric juice delays the appearance of a sufficiently strong acid reaction of the contents near the pylorus and thereby delays the first opening of the pylorus.[11] If protein food is diluted with water there is evidently, in a given amount of the food, less protein to unite with the acid than would be present if the same amount were given undiluted.

Lean beef of standard consistency gives the following average figures:

Hours after feeding	½	1	2	3	4
Cm. in small intestine	1.5	2.5	16	22	24.5

When lean beef, shredded and mixed with water to a thin gruelly consistency, was fed, the following figures resulted:

Hours after feeding	½	1	2	3	4
Aggregate length, in cm., of food masses in the small intestine	0	11	20	23	29
	7	9	30	30	28
	0	20	32	33	32
	5	8	22	32	30
	6	22	35	38	37
	0	8	29	39	32
	8	21	33	38	36
Average (7 cases)	3.5	14	28.5	33	32

A comparison of the figures in the foregoing tables and the curves in Fig. 2 shows that the dilution of the protein food, and the reduction thereby of the material uniting with the acid of the gastric juice, tends toward a more rapid discharge of the protein from the stomach.

Schüle[12] states in connection with his investigation of the discharge of liquids that fluid foods seem to increase the motility of the stomach. An inference to the same effect can be drawn from

[9] Loc. cit., p. 590.

[10] The slow emergence of beer and bouillon, compared with water, can be explained by the effect of these fluids in stimulating the flow of gastric juice (see Pawlow, The Work of the Digestive Glands, London, 1902, p. 138 et seq.) and the resultant closure of the pylorus through the acid reflex from the duodenum.

[11] Cannon, Amer. Jour. Phys., 1907, xx, 292.

[12] Ztsch. f. klin. Med., 1896, xxix, 73.

Moritz's statement: "Solid food causes a checking of gastric peristalsis, which overcomes the stimulating effect otherwise exerted upon it by water." We have never noted any significant changes in peristalsis due to variations in consistency.

2. *The Influence of Hard Particles in the Food.* There are numerous clinical reports of foreign bodies swallowed accidentally or wilfully by children and demented persons, and in some instances by normal adults. Eckold[13] reviews more than seventy such cases in which objects of the most varied size and character were swallowed. When they remained long in the stomach more or less serious derangement of gastric functions resulted, followed by malnutrition and in a large percentage, by death. The stomach may evidently function, though imperfectly, while containing a foreign body. But these cases represent decidedly abnormal conditions, and do not throw much light on conditions that may be classed as more or less common, such as the presence in the stomach of bone, seeds, and poorly masticated food.

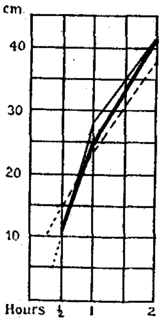

FIG. 1

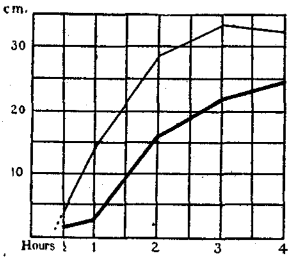

FIG. 2

FIG. 1.—These and the following curves show the average aggregate length of the food masses in the small intestine at designated intervals after feeding. The light continuous line is the curve for potato of standard consistency; the heavy continuous line, for thick doughy consistency; the broken line, for thin gruelly consistency.

FIG. 2.—The heavy line is the curve for lean beef of standard consistency, the light line that for lean beef of thin gruelly consistency.

Few observations as to the relation between hard food masses and gastric discharge have been reported. Schüle[14] states that coarse food remains in the stomach longer than food of smoother consistency. Moritz[15] has described experiments on a dog with a duodenal fistula, in which finely chopped sausage began to leave the stomach in forty-five minutes, whereas coarse unchopped sausage did not begin to leave for two hours, and then appeared at the fistula in a "soaked slippery condition." Cannon[16] reported in his

[13] Inaugural Dissertation, Greifswald, 1896.

[14] Loc. cit., p. 75.

[15] Verhandl. der deut. Naturforscher und Aerzte, 1893, p. 25.

[16] Amer. Jour. of Phys., 1898, i, 359.

first paper on the stomach that hard particles repeatedly pushed up to the pylorus checked the outgo of food from the stomach. The method used in the present investigation permits a more careful testing of this conclusion.

As hard particles, small irregular pieces of starch paste were used. Ten per cent. starch paste, mixed with subnitrate of bismuth, was cut into cubes and set aside to dry. From fifteen to twenty of these dried cubes, 1 to 5 mm. in dimension, were given mixed with the standard potato. In the first four cases reported below the the particles, which had dried for two weeks, were very hard. In the other cases the particles dried only two to four days.

Hours after feeding	½	1	2
Aggregate length, in cm., of the food masses in the small intestine[17]	4	5	14
	0	3	9
	2	5	7
	0	0	0
	7	13	23
	0	8	22
	0	8	25
	4	13	20
	2	16	21
	1	13	23
Average (10 cases)	2	8.5	16.5

In Fig. 3 the normal discharge is compared graphically with the discharge when the same food, with hard particles added, is fed. As the figures and the curves show, there is a marked retardation of the outgo of food from the stomach when hard particles are present. In the first four cases the outgo was clearly slower than in the others, as if the harder particles had had an inhibitory effect until softened. The checking action of the softer particles, however, shows likewise the working of a mechanical factor in modifying the normal mechanism at the pylorus.

The hard particles with a large bismuth content could be seen on the fluorescent screen as small black shadows against the less dark background of the shadow of the stomach. The to-and-fro oscillations of the small masses in the antrum already described[18] were repeatedly observed. There is a discrepancy between the immobility of these particles in the cardiac end of the stomach, as described in the earlier paper, and Beaumont's report that food circulates down along the greater and up along the lesser curvature. It is conceivable that the difference of observation might be due to a difference in the consistency of the food—that circulation might occur in a fluid gastric content, but not in a semisolid mass.

Starch paste of the consistency of thin gruel, with bismuth sub-

[17] In several cases, notably Case 4, there was an accumulation of gas in the stomach. The presence of the gas tended still farther to check the rate of the discharge.

[18] See Cannon, Amer. Jour. of Phys., 1908, i, 369.

nitrate added, was given. Several (3 or 4) of the hardened starch particles were then swallowed by the animal. In all the experiments the particles lay along the lesser curvature, until gradually carried toward the pylorus. There was no evidence of a circulation of the gastric contents such as Beaumont described.

3. *The Influence of Coarse Graham Bread.* There is evidence that food containing spicules of bran, such as coarse graham bread, may stimulate peristalsis in the large bowel and thus prevent constipation. It was of interest to determine whether gastric peristalsis and the discharge from the stomach are affected by food of this character. There are statements in the literature that no appreciable difference exists between whole meal and white bread in the duration of their stay in the stomach. Penzoldt[19] remarks, however, that light bread remains in the stomach as long as black bread and longer than bread made of coarse meal.

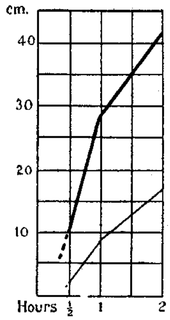

FIG. 3

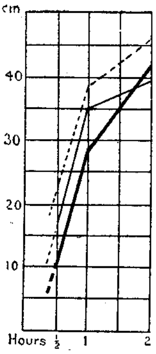

FIG. 4

FIG. 3.—The heavy line is the normal curve for potato; the light line, the curve when hard particles are present in the food (10 cases).

FIG. 4.—The heavy line is the normal curve for potato, the light line that for white bread (7 cases), the broken line that for graham bread (11 cases).

In the observations on the rate of discharge of bread, common white bread obtained at a bakery was used as a control instead of potato. The bread was prepared, however, just as in the observations with potato, and the same proportion of bismuth subnitrate was added. The following are the figures for white bread:

Hours after feeding	½	1	2
Aggregate length, in cm., of the food masses in the small intestine	10	30	41
	26	40	33
	15	33	30
	20	35	46
	19	42	41
	10	30	36
	16	36	49
Average (7 cases)	16.5	35	39.5

[19] Deut. Archiv. f. klin. Med., 1893, li, 560.

The graham bread fed in the first eight of the following cases was not so coarse as that fed in the last three cases:

Hours after feeding	$\frac{1}{2}$	1	2
Aggregate length, in cm., of the food masses in the small intestine	23	44	48
	30	45	49
	35	42	33
	24	47	48
	16	45	49
	25	24	46
	25	37	44
	19	40	50
	10	33	51
	16	25	44
	25	34	45
Average (11 cases)	22.5	38	46

A graphic comparison of these results with the results when potato is fed is shown in Fig. 4. The curves and the tables reveal a slightly slower rate of discharge for white bread than for potato, and a more rapid discharge for graham bread than for either of the other foods.

In summarizing the effects of the consistency of food on its discharge from the stomach, it may be fairly stated that within limits more or less water added to carbohydrate food does not change the rate of outgo, though dilution hastens the outgo when protein is fed; that hard particles in the food distinctly hinder the discharge from the stomach; and that coarse branny food is forced through the pylorus at a slightly more rapid rate than are similar foods finer in texture.

THE INFLUENCE OF GAS IN THE STOMACH. The common use of carbonated water has led to attention being paid to the effects of carbon dioxide on the functions of the stomach. There is fair unanimity of testimony that this gas stimulates both secretion of hydrochloric acid and gastric peristalsis.[20] That the presence of a body of gas in the stomach might affect the exit of food has apparently not been much considered. Yet with the x-rays gastric peristalsis may be seen moving over an accumulation of gas without either churning the gastric contents or propelling them onward. The gas acts as a shield, keeping the walls of the stomach away from the food. We desired to learn what might be the effect of a considerable amount of gas in the stomach on the discharge.

The animals were fed the standard amount of food, and then air was blown into the stomach. In the first experiments the volume of air introduced was measured, but this procedure proved to be of little use, for eructations soon changed the original quantity. In all but the first four of the following cases the air was introduced

[20] See *Jaworski, Ztschr. f. Biol.*, 1883, xix, 443; 1884, xx, 234; *Gillespie*, Deut. med. Woch., 1887, p. 836; Penzoldt, Deut. Archiv f. klin. Med., 1903, p. 567.

while the animal was under x-ray observation; in these latter cases the distention of the stomach walls, which could be clearly seen, could be easily regulated. In a few instances eructations nearly emptied the stomach of air during the first hour; more air was then introduced until approximately the original volume was restored.

The following results were obtained:

Hours after feeding	½	1	2	3
Aggregate length, in cm., of the food masses in the small intestine	0	6	29	37
	9	34	44	44
	13	27	33	35
	14	24	34	40
	0	25	30	27
	0	30	33	24
	0	17	13	38
	0	17	31	33
	0	0	33	40
	14	26	36	38
	0	10	32	32
	3	6	22	29
	0	11	27	35
	0	10	24	32
Average (14 cases)	4	17.5	30	34.5

These average figures are compared with the average figures for normal conditions in Fig. 5. Examination of the table shows that there is, as was to be expected, a wide variation in the effects produced by the presence of gas in the stomach. In few cases, however, is there any effect except a retardation of the discharge into

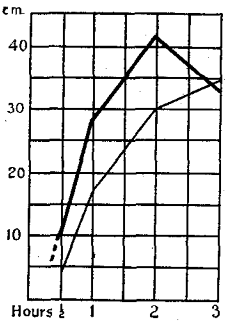

FIG. 5.—The heavy line is the normal curve for potato, the light line that for potato when gas is present in the stomach.

the intestine. This result has been noted repeatedly in other instances in which gas appeared in the stomach spontaneously. Thus, in one case in which fibrin was fed and in which the peristaltic waves could be clearly seen passing over the gas in the stomach the discharge was as follows:

Hours after feeding	½	1	2	3	4	5
Cm. fibrin, when gas present	0	0	0	10	17	22
Cm. fibrin, average of 4 normal cases	4	8	21	29.5	32.5	32

Such cases of spontaneous accumulation of gas seemed to be associated with gastric atony and enfeebled peristalsis. When the air was experimentally introduced, however, peristalsis, when observed, was normal in rate and intensity.

With peristalsis normal, how may the retardation of the discharge from the stomach, noted in the above experiments, be explained? That the distention of the gastric walls prevented them from exerting a direct propelling action on the food mass was distinctly to be seen. In a number of the observations of this series the food occupied relatively the position represented in Figure 6. There was direct contact between the stomach wall and the food only at one surface. Thus the gas prevented the churning of the food by the peristaltic waves and the gradual propulsion of the food through the pylorus.

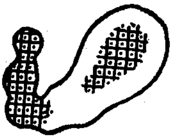

FIG. 6

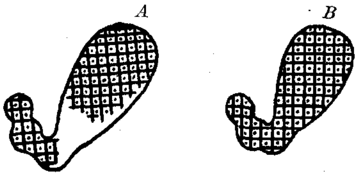

FIG. 7

FIG. 6.—Tracing of the outline of a stomach showing the separation between the walls and the food, caused by gas.

FIG. 7.—*A*. Tracing of the outline of a stomach showing a collection of gas in the pre-antral region. *B*. The same stomach after removal of gas.

The retardation of gastric discharge through the accumulation of gas in the stomach is a result which evidently might be different in man and in the cat. In the upright position of man any gas in the stomach would naturally rise to the fundus, and the food would then be in the region of active peristalsis. Furthermore, the gas might thus be readily voided by eructation. But in the prone position of man gas in the stomach may render peristaltic activities quite as ineffective as it does in the cat.

In connection with these observations there has been observed repeatedly in the pre-antral region an apparently empty space at about the position indicated in Fig. 6. Magnus[21] described a similar appearance in the stomachs of morphinized cats. He attributed the appearance to a persistent constriction of the gastric wall in this region. On two different occasions when we noted this appearance (Fig. 7, *A*) we passed a tube down the œsophagus and into the stomach, watching by means of the fluorescent screen its exact course. When the tube reached the light area, the area disappeared, and when the tube was withdrawn the shadow of the stomach presented a uniform dark appearance (Fig. 7, *B*). The light area was apparently due to gas which was carried off by the tube.

[21] Archiv f. die ges. Phys., 1908, cxxii, 254.

THE INFLUENCE OF HEAT AND COLD. The possible effects of heat and cold on the secretory and motor functions of the alimentary canal have been studied by various methods. Lüderitz[22] exposed the stomach and intestines of rabbits in a bath of normal salt solution which was gradually cooled. He saw no change in the motor activity until a temperature of 28° to 30° C. was reached. In one case very vigorous peristalsis was seen at 29° C. Below 28° the movements ceased. Oser[23] states that low temperatures close the pylorus, but that higher temperatures, up to 37° C., have no such effect. According to Müller,[24] low temperatures have a quieting, even a paralysing effect on the movements of the stomach, whereas high temperatures increase gastric peristalsis. These observations are in accord with those of Schüle,[25] who found that water at 45° left the stomach much faster than water at 0° or 28° C., but they do not seem to accord with Müller's own results that hot and cold fluids leave the stomach more slowly than fluids at body temperature.

The effect of temperature variations on secretion has been little studied. Cahn[36] reports that when he fed powdered meat with water at 15°, 1 to 1.3 p.m. of HCl was secreted during the first hour, and that with the water at 45° the acid was up to 1.8 p.m. Both these results, however, are lower than the results when temperature is normal. Micheli[27] in a study of the gastric secretion in ninety patients found that with water at 35° to 37° the secretion was greatest, at 45° to 50° least, and at 2° to 4° greater than at room temperature. A similar stimulating effect of cold water was noted by Jaworski.[28]

In such studies as are above cited the time required for the equalization of the temperature of the body and of the ingested food is especially significant, for it is probable that the temperature effects diminish as the equalization takes place. By use of maximum thermometers, Winternitz[29] observed that thirty minutes after drinking 500 c.c. of water at 5° to 7° the temperature of the gastric contents was only 0.6° C. lower than general bodily temperature. On a patient with gastric fistula Quincke[30] obtained similar results when cold water was taken, and further found that water at 40° C. reached body temperature within ten minutes. According to Quincke, hot or cold water reaches body temperature sooner than lukewarm milk. As Müller points out, the stomach is in a high degree able to bring food of widely differing temperature quickly to the tem-

22 Virchow's Archiv, cxvi, 53.
23 Ztschr. f. klin. Med., 1892, xx, 287.
24 Ztschr. f. diät. und physikal. Ther., 1904, viii, 587.
25 Ztschr. f. klin. Med., 1896, xxix, 81.
26 Ztschr. f. klin. Med., 1887, xii, 36.
27 Archiv ital. di clin. med., 1896. Referat, Archiv f. Verdauungs-Krankheiten, 1897, iii, 244.
28 Deut. Archiv f. klin. Med., 1884, xxxv, 76.
29 Physiologic Bases of Hydrotherapy, in A System of Physiologic Therapeutics, Philadelphia, 1902, ix, 41.
30 Archiv f. exper. Path. und Pharm., 1888, xxv, 380.

perature of the body, a function doubtless dependent on the central position of the organ in the body and to the rich blood supply in its walls and in the surrounding structures.

Since the stimulating influence due to variations of temperature is present for only a comparatively short interval, the influence exerted might be correspondingly short; but the possibility of the effect outlasting for some time the period of stimulation must be considered. In the following experiments to determine the rate of discharge of hot and cold solid foods, the conditions of experimentation were quite normal. Care was taken to keep the food at the temperature stated until all had been fed.

In two cases in which the hot food was given the potato was kept in a dish surrounded by a large quantity of water at 50° to 55° C. during the period of feeding, and the animals were fed from a spoon. In the other cases the food was given by means of a syringe, and was delivered into the stomach at a temperature of approximately 60°. The cold food was fed in a frozen condition, and reached the stomach in frozen lumps.

The following results were obtained:

HOT FOOD, 50° to 60°.

Hours after feeding	$\frac{1}{2}$	1	2
Aggregate length, in cm., of the food masses in the small intestine	13	27	48
	10	38	45
	14	31	43
	12	31	45
	18	38	45
Average (5 cases)	13.5	33	45

COLD FOOD, FROZEN.

Hours after feeding	$\frac{1}{2}$	1	2
Aggregate length, in cm., of the food masses in the small intestine	10	29	50
	18	43	49
	19	38	39
	14	34	44
	12	38	44
	12	25	52
Average (6 cases)	14	34.5	46.5

As the tables and the curves (Fig. 8) indicate, the only change from the normal in the rate of discharge of food, hot or cold, is a slight acceleration, but this change is so slight as to be inconsiderable. In none of the cases was there observed any notable variation from the usual peristalsis.

In a series of observations made by Mr. C. R. Metcalf in this laboratory, hot and cold applications applied from 1 to 40 minutes to the abdomen of healthy cats produced no appreciable alteration in gastric peristalsis. It continued without interruption and without evident change of rate as measured by a stop watch. On the other hand, as already reported,[31] excessive cooling of the stomach

[31] Cannon and Murphy, Annals of Surgery, 1906, xliii, 531.

and intestines, by introducing cold sterile salt solution into the abdominal cavity, may be followed by increased activity of intestinal peristalsis. But this is a procedure causing changes of temperature in the bowel too great to be produced by any external applications.

The conclusion seems justified that changes in the temperature of the food do not influence for any length of time either gastric peristalsis or the rate of discharge of solid food from the stomach.

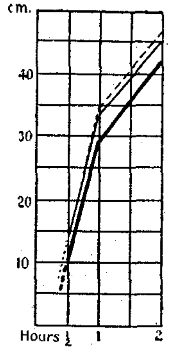

FIG. 8.—The heavy line is the normal curve for potato, the light line that for potato fed hot and the broken line that for potato fed cold.

THE INFLUENCE OF HYPERACIDITY. The earlier literature contains many conflicting statements regarding the relation between gastric motility and the secretion of HCl. Reigel,[32] Kussmaul,[33] and others express the idea that through abnormal acidity the pylorus is kept spastically closed. Similarly, Moritz[34] found in experimenting on himself that 500 c.c. of 0.95 per cent. HCl was more slowly expelled from the stomach than the same amount of water. Some of the earlier investigators regarded the acid of the gastric juice as the real stimulus to peristalsis. Later observations, however, have shown that peristalsis may be present even when the gastric contents are neutral or even alkaline.

The part played by HCl in controlling the discharge of food from the stomach and in stimulating the flow of pancreatic juice has recently been emphasized. The pylorus remains closed until an acid reaction appears in the chyme on the gastric side of the sphincter; it then opens to permit the exit of some of the chyme. Thereupon the acid chyme in the duodenum closes the sphincter, and keeps it closed until the pancreatic juice and bile, caused to flow by the presence of acid in the duodenum, have neutralized the chyme. Then and only then does the pylorus open again and let out more of the stomach contents.[35] In accordance with this explanation

[32] Ztschr. für klin. Med., 1886, xi, 17.
[33] Deut. Archiv für klin. Med., 1869, vi, 460.
[34] Loc. cit., p. 570.
[35] Cannon, Amer. Jour. Phys., 1907, xx, 293.

of the control of the pylorus, hyperacidity might very well cause a retardation of gastric discharge, but it would do so because longer time would be required for neutralization in the duodenum, and the pylorus would therefore be held closed for longer periods. It is of interest to inquire as to the effects of hyperacidity on the rate at which food leaves the stomach. To obtain evidence on this question cats were fed potato with which had been mixed a known percentage of HCl.

In determining the acidity boiled potato was mashed without the addition of water and then concentrated acid was added. Thus, for 1 per cent. acidity, 4.2 c.c. HCl with specific gravity 1.185 (*i. e.*, about 34 per cent.) was added to 100 c.c. potato, weight 140 grams. For the other percentages of acidity the corresponding fraction of this amount of acid was accurately measured and mixed with the potato. The following are the results obtained:

0.25 PER CENT. HCL.

Hours after feeding	½	1	2
Aggregate length, in cm., of the food masses in the small intestine	24	47	72
	25	35	48
	28	40	55
	34	63	64
	22	40	60
	40	52	61
Average (6 cases)	29	46	60

0.5 PER CENT. HCL.

Hours after feeding	½	1	2
Aggregate length, in cm., of the food masses in the small intestine	25	40	58
	25	41	58
	17	34	46
	20	38	49
	20	35	56
	18	30	47
Average (6 cases)	21	36.5	52

1 PER CENT. HCL.

Hours after feeding	½	1	2
Aggregate length, in cm., of the food masses in the small intestine	8	20	34
	9	16	46
	13	35	43
	9	30	72
	14	27	50
	15	19	40
Average (6 cases)	11.5	24.5	47.5

In comparing with the normal conditions these results of feeding acid food, it is fairer to use the second rather than the first half-hour of the normal curve as a standard, since at the beginning of the first half-hour digestion has not begun and no acid has yet appeared at the pylorus, while at the beginning of the second half-hour acid chyme is being discharged. As the curves (Fig. 9) and as the tables indicate, the rate of exit is faster than normal when the potato has an acidity of 0.25 per cent., and slower than normal when it has an acidity of 1 per cent. Potato with an acidity of 0.5 per cent. is discharged during the first half-hour about as rapidly as the food is normally discharged. The difference between the outgo of the weakly acid (0.25 per cent.) and the strongly acid (1 per cent.) potato is remarkable. Note that at the end of the first half-hour there was in the intestine more than two and a half times as much, and at the end of an hour about two times as much of the weakly acid potato as of the strongly acid. The rapid exit

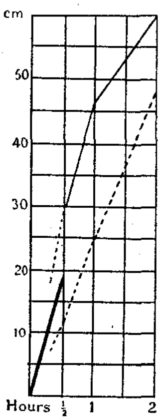

Fig. 9.—The heavy line is the curve (for the second half-hour) when potato is fed normally; the light line, when fed with 0.25 per cent. acidity (HCl); and the dotted line, when fed with 1 per cent. acidity.

was confirmed by the appearance of the stomach: in several instances the stomach was practically empty at the second observation—a condition normally never seen. The appearance of the food masses in the intestine was also characteristic, for long, continuous coils of food were regularly observed.

In all the experiments on the feeding of acid food gastric peristalsis was especially deep and rapid. The rate was usually slightly faster than six waves per minute. In one instance, at the half-hour observation, the waves passed so rapidly as to attract attention. On timing them with a stop-watch twenty waves were seen to move over the antrum in sixty-six seconds, more than eighteen per minute. This rate was so much faster than normal that the counting was repeated, with the same results. At the one-hour observation and thereafter, however, the waves passed at the usual rate.[36]

[36] Opportunity was offered to note the rate of gastric peristalsis in four kittens about six weeks old. The number of waves per minute was within the limits observed in adult animals. The rate of discharge from the stomach was likewise not remarkably different from the rate observed in adults.

THE INFLUENCE OF MASSAGE. The animals selected for observations on the effect of massage were especially docile; they were thus selected in order that the manipulation might not enrage them and thereby introduce as a complicating factor the inhibitory influence of a strong emotional state. Most of the time purring indicated a peaceful tranquillity. Massage was applied by gently kneading the abdomen, especially under the last ribs, as the animal was lying comfortably on its right side. None of the animals was massaged all the time between observations, but of six, four were massaged one-fourth of the time and two one-half of the time. In spite of this extensive manipulation there was no considerable change in the rate of gastric discharge. The average figures for the first three regular observations were 12, 25, and 36 cm., instead of the normal 10, 28, and 41.5 cm. The gastric peristaltic waves, which passed at the usual rate, were notably deep. Segmentation in the small intestine was also quite marked.

THE INFLUENCE OF IRRITATION OF THE COLON. It has recently been shown that resection of the small intestine some distance below the pylorus results in such strong and continuous contraction of the pyloric sphincter that, in spite of vigorous peristalsis, food may not begin to leave the stomach for four or five hours after feeding.[37] It is of interest to know how far along the alimentary canal such irritation may reflect its influence on the stomach. The clinical observation that inflammation of the appendix may disturb gastric digestion indicates the possibility of effects on one part of the canal from abnormal conditions in a relatively remote region. The following experiments were tried with the purpose of determining whether irritation of the colon would influence the exit of food from the stomach. In these experiments croton oil was used as an irritant. In no case did the animal show signs of discomfort from the procedure.

Five cats, a few hours after receiving a cleansing enema, were fed 25 c.c. potato and were then injected per rectum with 50 c.c. sweet oil containing 1.25 c.c. croton oil. When observed, the peristalsis of both the stomach and intestine seemed unusually vigorous. The stomach was peculiarly elongated. The rate of discharge may be judged from the following table:

Hours after feeding	$\frac{1}{2}$	1	2
Aggregate length, in cm., of the food masses in the small intestine	23	39	39
	0	1	16
	16	17	33
	0	5	19
	0	12	22

The irregularities of the figures in the above table can perhaps be explained on the impossibility of clearing the colon and the

[37] Cannon and Murphy, loc. cit., p. 516.

consequent uncertainty as to the degree of dilution of the irritant by the contents of the bowel. Three of the five cases, however, showed a marked slowing of the discharge.

In order to control conditions more exactly, four cats were etherized, and, under aseptic precautions, a few drops of croton oil injected into the cecum through a small median incision in the abdominal wall. The next day they were fed the standard potato and observed. In all the animals gastric peristalsis was vigorous, but in none of them was there any discharge into the intestine during the first half-hour. In two cases gas appeared in the stomach at the end of the fourth hour, and in one of these cases so much gas accumulated that the distended stomach caused stretching of the abdominal wall and some respiratory difficulty. In another case the first food to enter the colon passed into it during one of the observations. The small mass was forced into the large intestine and pushed upward a short distance, whereupon it was violently segmented for a few moments. Thirty minutes later no more food had entered the large intestine, but a large solid coil of food, the shadow of which was about 17 cm. long, seemed to be blocked immediately before the ileocolic valve. The colon was filled with gas so that its outline was clearly visible. The following table shows the results of these experiments:

Hours after feeding	$\frac{1}{2}$	1	2	3	4	5	6	7	8
Aggregate length, in cm., of the food masses in the small intestine	0	0	9	25	34	34	37	45	40
	0	6	32	44	45	33	47	44	49
	0	0	6	18	21	39	41	45	51
	0	8	8	30	29	33	32	41	37
Average (4 cases)	0	3.5	13.5	29	32	35	39	43.5	44

Comparison of these figures with the figures from normal cases (Fig. 10) shows at once remarkable differences. Not only is the gastric discharge much slower when the colon is irritated, but the passage of the food through the small intestine is greatly retarded, The curve drops mainly because of the passage of material into the large intestine. Note that when the colon is irritated the curve fails to drop throughout eight hours, whereas the normal curve begins to drop at the end of two hours. Normally potato begins to appear in the colon at the end of two or three hours; under the condition of the present experiment, however, it did not appear in the colon until six or seven hours had elapsed. In all cases food was still present in the stomach at the end of seven hours, though normally the stomach is emptied of this food in about three hours.

To prove that the effects noted above were not due to the operative procedure alone, four cats were operated upon as before, and, instead of croton oil, a few drops of water were injected into the colon. In two of the cases the gastric discharge on the next day was somewhat delayed, but not nearly so much delayed as when croton oil was injected; the other two cases were close to the normal.

The conclusion is justified that irritation of the colon can cause marked retardation in the rate of exit of food from the stomach *and in the passage of food through the small intestine.*

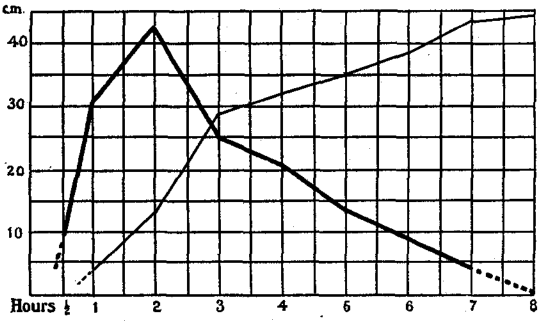

FIG. 10.—The heavy line is the normal curve for potato, the light line the curve when croton oil has been injected into the colon.

SUMMARY. If carbohydrate food is thinned by adding water, there is, within limits, very little change in the rate of exit from the stomach; but adding water to protein food tends to make the discharge more rapid. When hard particles are present in the food the rate of outgo from the stomach is notably retarded. Coarse branny food leaves the stomach slightly faster than similar foods of finer texture. The presence of gas in the stomach delays gastric discharge, an effect due to the gas preventing the walls of the stomach from exerting the normal mixing and propelling action on the food. No considerable variation from the normal rate of exit from the stomach is observed when the food is fed very hot or very cold. Food with approximately normal acidity leaves the stomach much faster than food which is hyperacid (1 per cent.), a result in harmony with other observations on the acid control of the pylorus. Feeding acid food is followed by deep and rapid peristalsis. Massage of the stomach, even when extensive, has very slight influence on the passage of food through the pylorus. Irritation of the colon (with croton oil) notably retards gastric discharge and delays the movements of food through the small intestine.