

## STUDIES IN THE VARIATIONS OF THE TONUS OF THE GASTRIC MUSCULATURE IN HEALTH AND DISEASE \*

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NEW YORK

The alterations in structure of any of the body organs, when produced by disease, are of greatest clinical importance when accompanied by disturbances in the function of the involved part. The function of the musculature of the stomach, that is, its motor function, is one of the most essential attributes of that organ; disturbances of this function characterize many of the earliest stages of gastric diseases. In this paper we have attempted to correlate the results of our studies on the variations of the functions of the gastric musculature in diseased conditions. Kymographic methods were utilized in their demonstration, as described by Cannon and Washburn<sup>1</sup> and by Carlson<sup>2</sup> and his associates, and studies of gastric hunger contractions and gastric tonus were carried on.

### HISTORICAL

In 1877, von Pfungen<sup>3</sup> demonstrated, in the antrum of the stomach of animals, contractions occurring regularly three times a minute.

Morat,<sup>4</sup> in 1882, made use of a rubber balloon attached to the end of a stomach tube and recorded intragastric pressures. His tracings evidenced respiratory, cardiac and gastric elements.

In 1895, Moritz<sup>5</sup> obtained readings of intragastric pressure under various conditions. He utilized the method of an inflated balloon attached to a stomach tube, which he introduced into the stomach. The normal pressure within the healthy stomach of man varied between 2 and 16 cm. of water. He demonstrated a difference in pressure between the antral and fundic portions of the stomach, and made some observations on himself after the administration of such drugs as

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\* Submitted for publication March 30, 1917.

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\*\* This study was carried on under the tenure of a George Blumenthal, Jr., Fellowship in Pathology.

1. Cannon and Washburn: *Am. Jour. Physiol.*, 1911-1912, **29**, 441.

2. Carlson, A. J.: *Am. Jour. Physiol.*, 1912, **31**, 175 and 221; *ibid.*, 1913, **32**, 245.

3. Von Pfungen: *Centralbl. f. Physiol.*, 1877, p. 220.

4. Morat: *Arch. de Lyon méd.*, 1882, p. 882.

5. Moritz: *Ztschr. f. Biol.*, 1895, **24**, 313.

bicarbonate of soda and tartaric acid. He recognized, both in the fasting and in the digesting stomach, the occurrence of contractions which followed one another three to three and one-half times each minute, which contractions continued for periods of fifteen to ninety minutes, and which were separated by intervals of rest. The presence of food in the stomach inhibited these contractions. By means of double balloons he was able to demonstrate activity in the antrum, which was synchronous with a state of rest in the fundus.

Ducchessi<sup>6</sup> applied the same method in animal experiments and found that an increase of intragastric pressure caused the appearance of rhythmic contractions. He showed distinct differences between contractions of the cardiac, fundic and pyloric parts of the stomach and confirmed in animals the presence of the rhythmic contractions described by Moritz in man. He was of the opinion that the empty stomach remained in a state of rest, but that the introduction of food or of the inflated balloon gave rise to the typical contractions which he observed. Excision of the celiac plexus was followed by a change in the contraction wave. With the occurrence of pathologic lesions a depression of gastric tone was observed.

Sick,<sup>7</sup> in 1906, employed a complicated apparatus by means of which he was able to obtain records of intragastric pressures and stomach contractions, and specimens of stomach contents for chemical examination. Using the facts obtained from normal subjects as criteria, he made observations also in pathologic conditions.

Boldyreff,<sup>8</sup> in exhaustive studies on the alimentary canal, demonstrated waves of contraction originating in the stomach and sweeping downward throughout the entire extent of the alimentary canal. They bore some relation to the empty state of the stomach, disappearing with the ingestion of food and reappearing some time later.

In 1911, Cannon and Washburn,<sup>1</sup> in the course of investigations on the cause of hunger, demonstrated periods of gastric excitability evidenced by peristaltic waves, which occurred synchronously with sensations of hunger. The conditions necessary for the appearance of these contractions were a tonic state of the neuromusculature, plus some increase in the intragastric pressure. The point of origin of these contractions was not fixed. Most important of all, Cannon and Washburn<sup>1</sup> maintained that hunger contractions were evidences of healthy tone in a normal stomach.

About a year later, Carlson<sup>2</sup> was fortunate in finding a man with a gastric fistula which allowed of physiologic investigations. In this man

6. Ducchessi: *Arch. ital. de biol.*, 1897, **27**, 61.

7. Sick: *Arch. f. klin. Med.*, 1906-1907, **88**, 169.

8. Boldyreff: *Zentralbl. f. Physiol.*, 1904, **18**, 489.

he was able to confirm all the statements of Cannon and Washburn.<sup>1</sup> He demonstrated in the kymographic tracings two types of contraction: one, a slow, periodic wave due to the normal tonal variations, which passed over the stomach three to four times a minute; second, a type of more powerful contractions, occurring in groups, lasting from fifteen

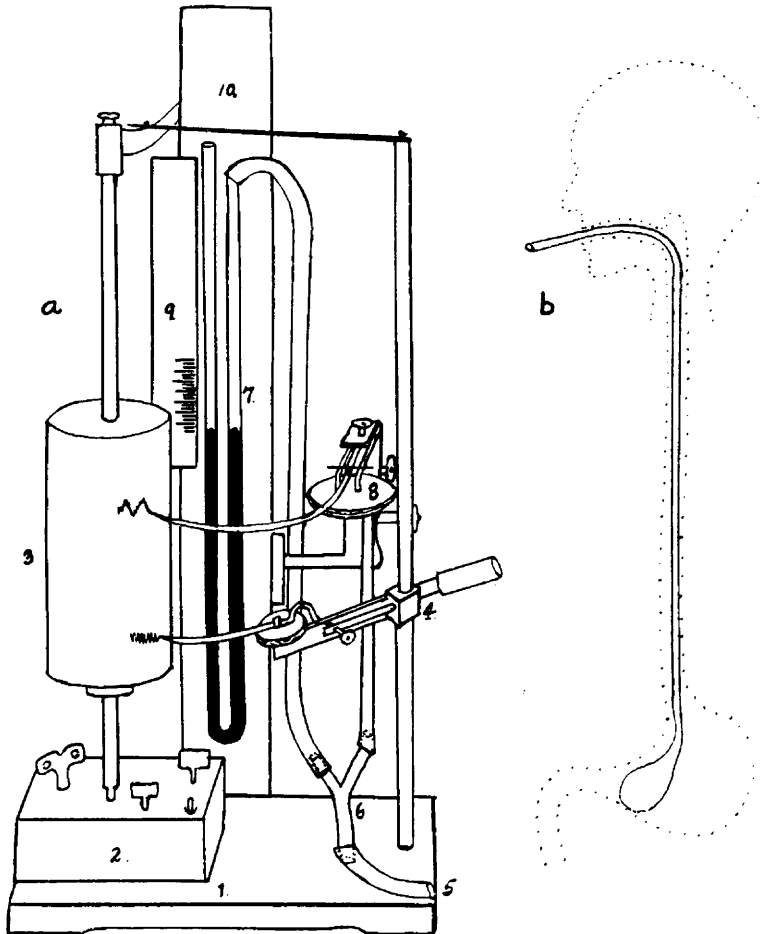


Fig. 1.—*a*, 1. Stand. 2. Clock work for revolving kymograph. 3. Kymographic drum. 4. Bracket supporting tambour and needle and connected with pneumograph about patient. 5. Tube connecting with balloon in patient's stomach and connecting with Y tube (6) to manometer (7) and tambour and needle (8). 9. Manometer scale. 10. Upright fixed to stand supporting apparatus. *b*, balloon and tube in stomach (diagrammatic).

to sixty or more minutes and separated by long periods of comparative inactivity. These last corresponded to the sensations of hunger and were easily inhibited by various causes, such as the act of swallowing or

the administration of various foods and drugs. The period of contractile activity was always accompanied by a period of slow gastric secretion.

We were enabled to apply this physiologic method in a series of pathologic cases in the hospital.<sup>9</sup> These cases included practically all the varieties of gastric diseases ordinarily encountered, such as gastric neuroses, gastric atony, vagotonia, secretory disturbances and organic lesions such as ulcer and carcinoma.

#### METHOD

A uniform technic was followed in all of these cases; an apparatus was used practically identical with that employed by Cannon and Washburn<sup>1</sup> and by Carlson.<sup>2</sup> The patient swallowed a collapsed toy balloon attached to the end of a narrow-caliber rubber tube. The free or proximal end of the latter was attached by a Y tube to both a mercury manometer and a tambour with its recording needle; the movements of the needle were in turn recorded on a slowly revolving drum. The respiratory element of the curve was controlled

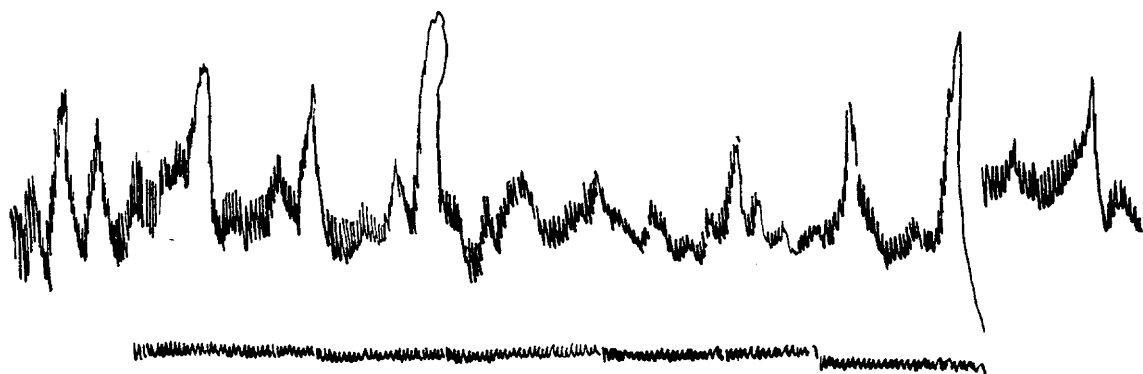


Fig. 2.—Kymograph tracings taken from normal individuals showing normal tonus and hunger contractions.

In this and the following figures the upper curve represents the gastric variations, the lower curve is a control obtained from a pneumograph fastened about the lower thorax and upper abdomen.

by a pneumograph fastened over the lower thorax and upper abdomen. Time was recorded manually in minutes. Observations were maintained for periods of from one-half hour to one hour and in cases where no contractions were observed in this time, the observation was repeated on a subsequent day. Extraneous influences, such as the presence of food, swallowed saliva, or other physical disturbances, were eliminated. In practically all instances the patients reposed quietly on the table, and frequently dropped off to sleep during the course of the observation. No record was accepted when the patient evidenced intolerance of the tube and balloon.

9. We acknowledge our indebtedness to Drs. Brill, Libman, Manges and Meyer of the first and second medical services of the Mount Sinai Hospital, and to Dr. Aronson, chief of the gastro-enterologic department of the dispensary, for their courtesy in permitting us to make these observations on the patients under their care.

## OBSERVATIONS

*Gastric Neuroses.*—These include those customarily seen in hospital ward or dispensary service. The records obtained from these patients did not vary particularly from those obtained from normal persons. That is, they evidenced normal tonal waves, recurring rhythmically and usually regularly, sometimes as slowly as once per minute, usually more rapidly, as two or three times per minute. The average tonal rise corresponded to about 5 mm. Hg. In the cases of neurosis the regular rhythm was sometimes disturbed by a varying degree of irregularity. The hunger contractions, which were always present in these organically sound stomachs, appeared singly or in groups. They were characterized by a steady rise of the lever, lasting over two or three respirations, until a pressure of 20 to 30 mm. Hg was registered, and following which there was a sudden drop to the base line. The rise of the lever

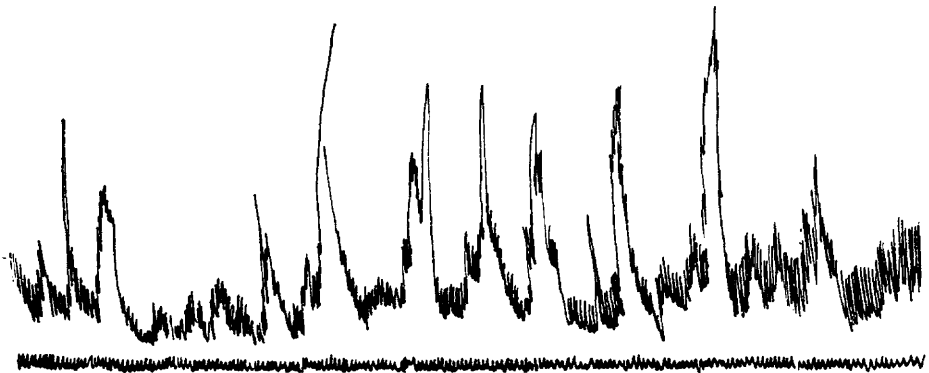


Fig. 3.—Tracing from a case of gastric neurosis, demonstrating good tone and continuous hunger contractions.

may be continuous, corresponding to a single powerful contraction, or may consist of several superimposed contractions. The fastigium is held for a fraction of a minute only. Occasionally, on the introduction of the balloon, no contractions appeared at first, but after a lapse of ten to twenty minutes the inhibitory influence of the foreign body passed away and tonal waves and hunger contractions made their appearance.

*Vagotonia.*—In a well marked case of vagotonia, hunger contractions predominated in the curve and demonstrated an extreme degree of excitability, the contractions following one another in rapid succession and without pause for comparatively long periods of time.

*Functional Secretory Cases.*—These include hyperacidities, subacidities and anacidities. These regularly show no disturbance in the motor function. Occasionally in marked instances of continuous hyper-

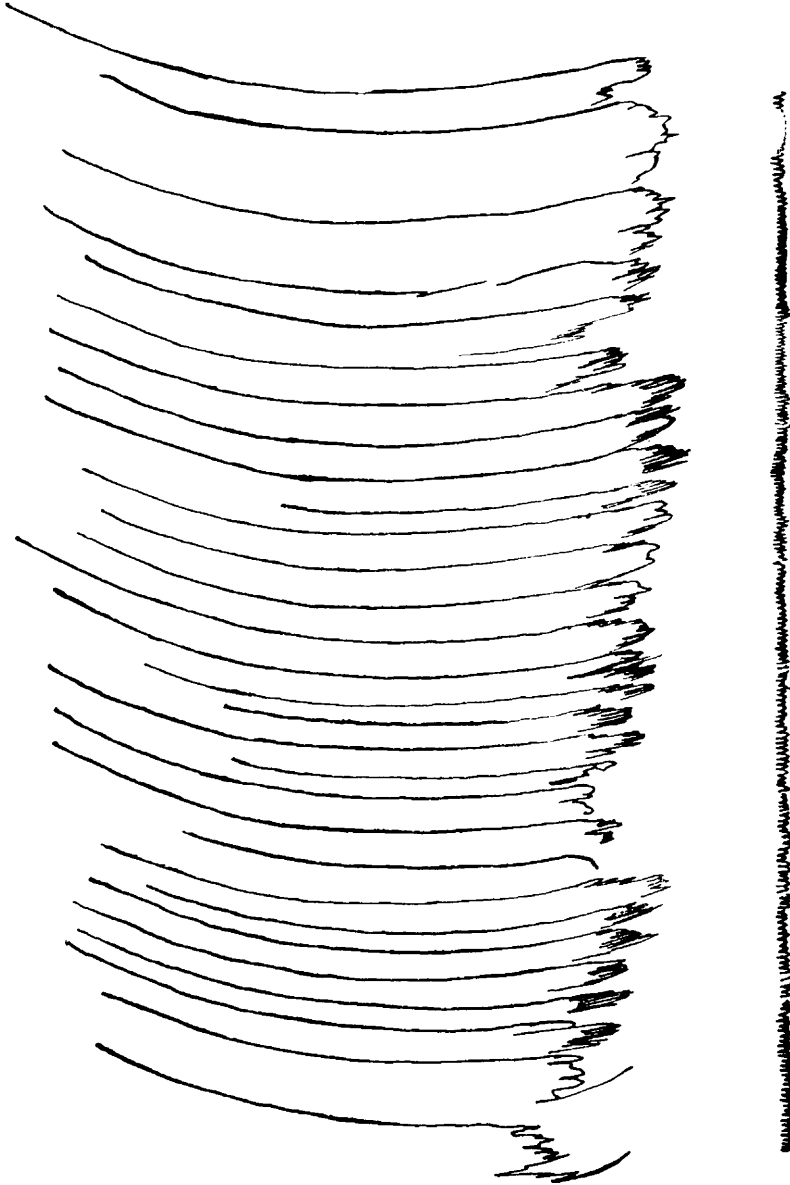


Fig. 4.— Case of vagotonia showing exaggerated, frequent and continuous hunger contractions; each hunger contraction is evidence of a rise in the intragastric pressure of 30 to 40 mm. Hg.

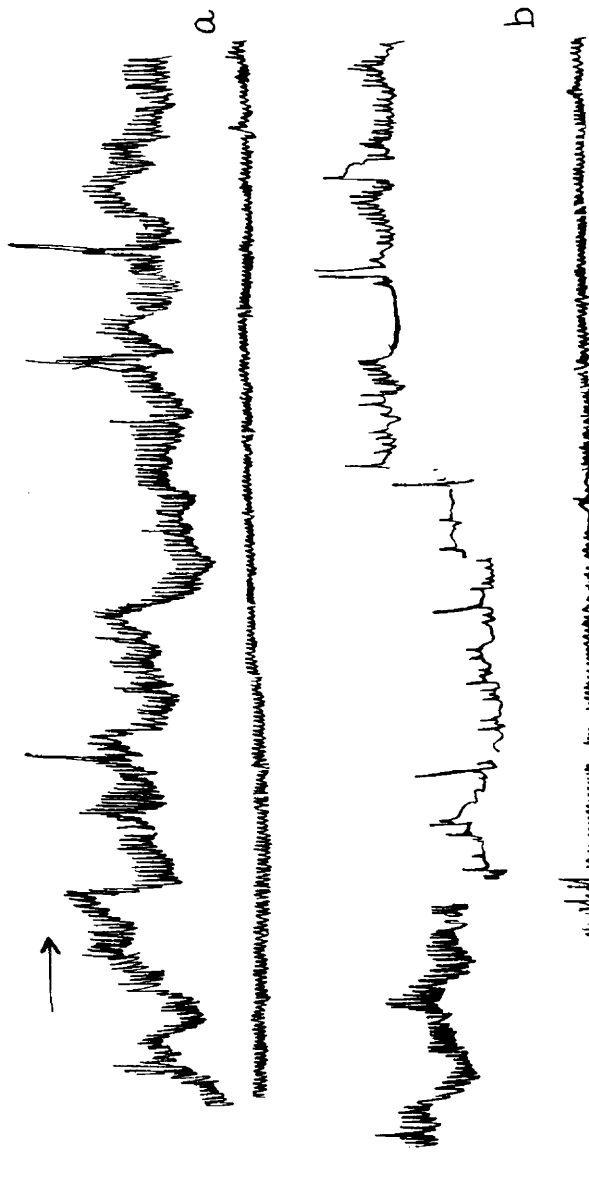


Fig. 5.—Tracing from a case of primary atony, showing progressive loss of tone (diminution and final disappearance of tonal waves). Duration of observation, one-half hour.



Fig. 6.—Tracing from case of ulcer (Type III) showing loss of normal hunger contractions; retention of tonal waves.

secretion, the constant presence of acid secretion in the fasting stomach inhibits the contractions, an appearance of atony being given.

*Primary Atony.*—This is evidenced by a diminution or disappearance of tonal contractions and a disappearance of hunger contractions. At the beginning of the observation moderate tonal contractions may appear, but these soon disappear and leave a curve which is characterized by absence of elevations and the maintenance of a continuous and unchanging level.

In cases of incompletely developed atony one occasionally may see small contractions or groups of moderate tonal waves, but the general curve as observed for the entire period is usually devoid of such demonstrations of tonus on the part of the gastric musculature.

Secondary atony accompanying organic lesions will be discussed under the appropriate headings.

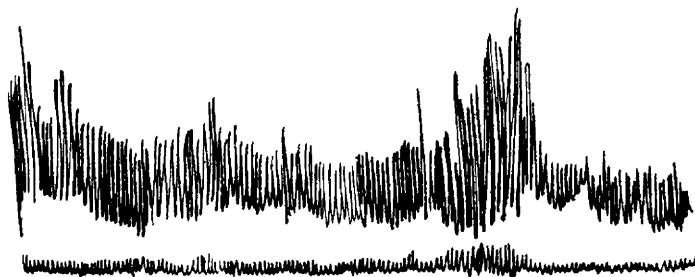


Fig. 7.—Atony secondary to callous ulcer on lesser curvature. Note complete absence of tonus and hunger waves.

We have not had an opportunity to study cases of pure gastritis. Catarrhal inflammations frequently complicate other anatomic lesions such as ulcer or carcinoma, and the descriptions of these conditions necessarily would include the effect of the catarrhal condition plus that of the main lesion. A case, however, has been reported in the literature<sup>10</sup> in which a gastritis was accompanied by a practically complete absence of motor activity.

*Gastric and Duodenal Ulcer.*<sup>11</sup>—No differentiating characteristics between these two types of ulcer could be demonstrated. It is of advantage to describe under different headings the tracings obtained.

1. Ulcer cases with practically normal tracings. These represent about one-fifth of the tracings.

2. Cases with retained tonal contractions, but irregular and isolated hunger contractions. These, too, represent about one-fifth of the cases.

10. Hamburger and Luckhardt: Jour. Am. Med. Assn., 1916, **66**, 1831.

11. This subject is described in detail by one of us in another article to be printed in the Annals of Surgery.



3. Ulcer cases, characterized by the disappearance of hunger contractions, but with retained tonus. These comprise also about one-fifth of the cases. Groups 2 and 3 together may be classed as those giving irregular tracings.

4. Cases of secondary atony. These are fewer in number. All gradations of this disturbance can be demonstrated. The presence of large, deeply punched out lesions in the body of the stomach has an inhibiting effect on the motor activity, and atonic conditions result. Pylorospasm is frequently associated with these large ulcers.

5. Cases of pyloric stenosis. In the early stages there is increased tonus and more prolonged and sustained hunger contractions. In the late stages a fatigue atony may appear. Between these two limits, all stages are observed.

*Carcinoma Cases.*—Here, too, the motility of the stomach may exhibit all changes from hyperactive conditions to marked degrees of atony. When the tumor is comparatively small, or when it is still limited to the superficial layers of the stomach wall, no disturbance is noticeable in the muscular activity. The tonus and hunger contractions are of normal volume and repeat themselves with the regularity customary to healthy stomachs. This is also true in the case of those tumors in the body of the stomach which may or may not be large in extent, but which are limited practically to the mucous membrane.

Tumors near the pyloric sphincter may be differentiated in accordance with the production or absence of a stenosis. In those cases with malignant stenosis, the same facts were observed as with the benign stenosis.

Carcinomata of the stomach are usually accompanied by various degrees of chronic gastritis, and in many cases the latter assumes a dominant position in regard to the disturbances of function and causes a practical disappearance of all muscular activity.

*Tabes with Gastric Crises.*—One such case has been studied, the observation being made during the intervals between attacks. The curve is one of complete incoordination, periods of marked overactivity following periods of atony with an absence of the normal rhythm. All of these phases were visible during a comparatively short period of observation.

#### DISCUSSION

The smooth muscle wall of the stomach is arranged in three layers and accomplishes a predominating churning motion in the fundus of the stomach and a predominating propulsive exertion in the antrum. In addition, there is provided a valve at both the entrance to, and the exit from, the stomach. Inasmuch as the natural tonicity of smooth

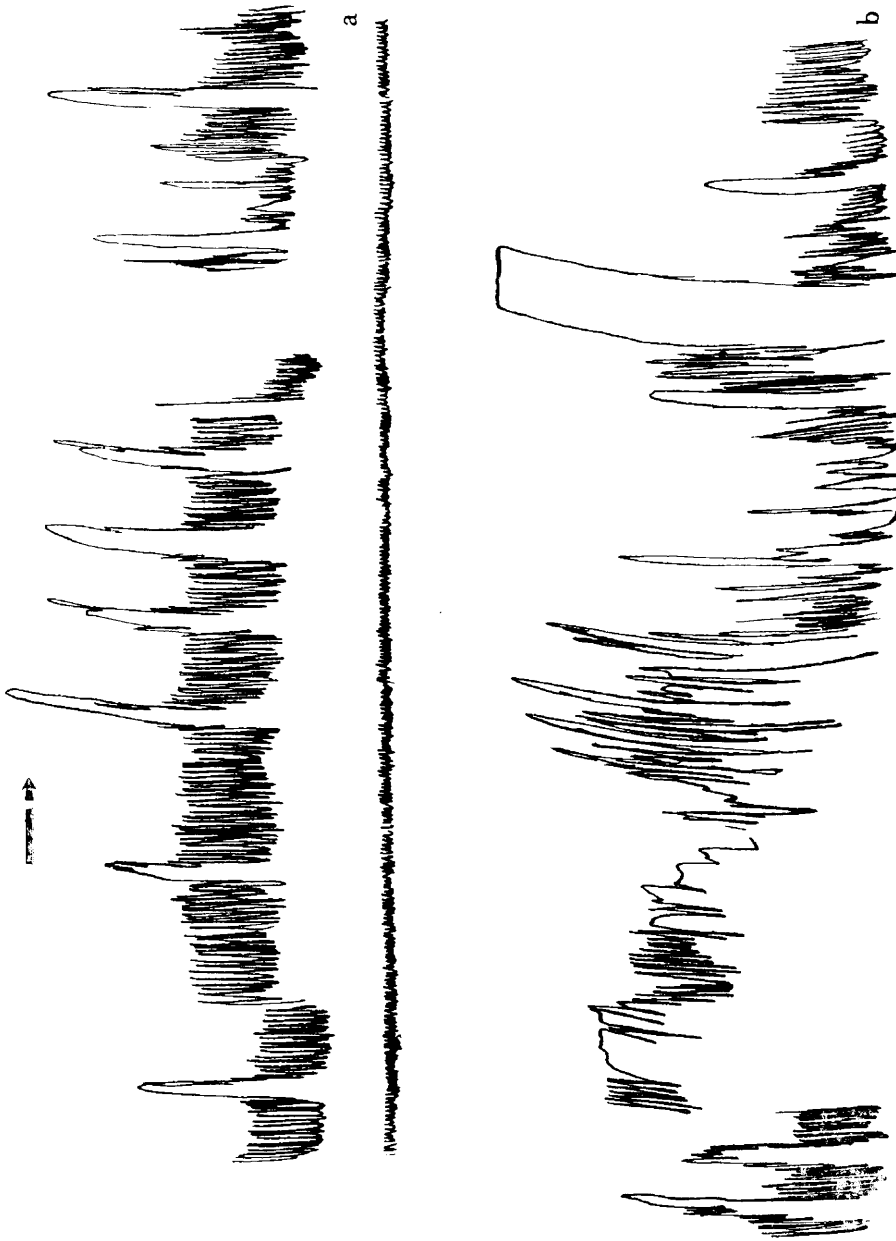


Fig. 8.—Benign pyloric stenosis. The hunger contractions are broader, more sustained and frequent. The middle tracing is the control.

muscle fiber is always in evidence, it follows that the entire structure is constantly in a state of contraction on its contents. The presence of valve formations at both ends of the stomach establishes conditions for intragastric pressures which would naturally vary with the activity of the organ.

This variation in the natural tension of the muscle fiber produces what has been called by Cannon and Carlson the "tonus contractions" of the stomach. In a healthy organ these tonal variations are repeated regularly and rhythmically three to four times each minute, and establish an intragastric pressure of an average moderate degree.

It has been conclusively shown in purely physiologic work that the appearance of any active contraction of the stomach is dependent on a normal tonus of the musculature, and has its origin in an increase in the intragastric pressure.

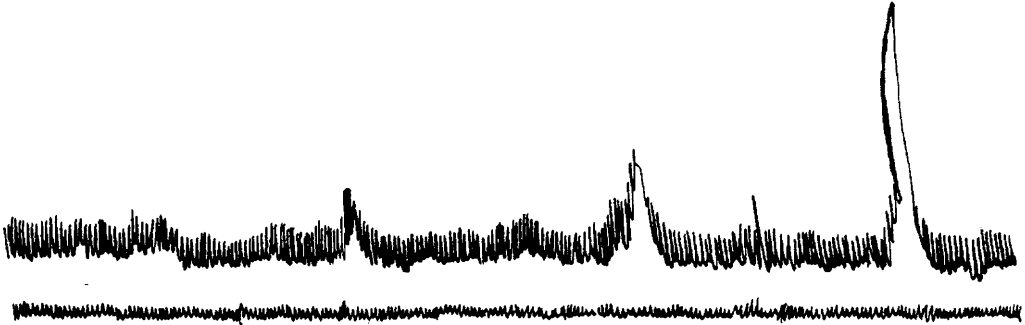


Fig. 9.—Same case as illustrated in Figure 8, taken six months later. Note that the tracing is now one of secondary atony, such as accompanies ectasia.

*Tonus Contractions.*—The tonus contractions which the kymographic drum records originate in the gastric musculature. Both Ducchessi and, more recently, Alvarez<sup>11a</sup> demonstrated like contractions of a spontaneous nature in excised portions of the stomach wall, the three portions of the viscus (cardia, fundus and antrum) each exhibiting a characteristic type of movement. With our technic, the introduction and inflation of the balloon, by raising intragastric pressure, gives rise to these typical tonus contractions, as explained by Cannon. That the contractions can arise either from the fundus or the antral portions, was clearly proved by Sick, who obtained contractions from both ends in the same person, the fundus contractions being weaker and of less amplitude than the antral. It is probable, however, that in the cases examined by us, the balloon, which, even when inflated, is only the size of a medium large lemon, moves easily in the stomach.

11a. Alvarez, W. C.: Jour. Am. Med. Assn., 1915, **65**, 388; *ibid.*, Am. Jour. Physiol., 1916, **41**, 321; 1916, **40**, 358; 1917, **42**, 422.

and is soon pushed down by the contractions to the antral region, where the larger hunger contractions are produced. Rogers and Hardt,<sup>12</sup> by enclosing a smaller balloon filled with bismuth within a larger inflatable balloon, demonstrated vigorous contractions at the fundus, sweeping down over the antrum. Alvarez<sup>13</sup> found the cardia and lesser curvature to be the most irritable portion of the stomach. Keith<sup>14</sup> suggested the presence of a rate-making node on the lesser curvature near the cardia.

The tonus contractions appear in all stomachs approaching the normal or acting in an efficient physiologic manner. They are diminished or absent in the following conditions:

*Gastric Atony.*—This refers to the simple atony often seen as part of the picture of a gastric neurosis, or to the atony secondary to pulmonary tuberculosis, secretory disturbances of the stomach, etc. The atony here may appear only after the lapse of ten to fifteen minutes of observation, or after the primary contractions incident to the introduction of a foreign body have subsided. In such an instance the atony is progressive. In tonic stomachs there may be inhibition at first, but soon the tonus contractions appear and are thereafter steadily maintained throughout the observation. In a tonic stomach the amplitude and rate of contraction are usually constant; in cases with disturbed tone, the contractions are irregular, unequal, and the rate often variable.

*Atony Secondary to Operation on the Stomach.*—This subject has been more fully described in a recent paper by the authors.<sup>15</sup> Suffice it to say that a pre-operative state of atony may continue after operation, particularly after gastro-enterostomy. The conclusions of the former paper were noted many years ago by Ducchessi<sup>16</sup> and Denechau.<sup>17</sup>

The recovery of tone in the cases benefited by operation is progressive and is strikingly illustrated by our curves.

*Ectatic Atony, or Atony Secondary to Pyloric Obstruction.*—Such an atony appears as a late stage of mechanical pyloric obstruction, or is secondary to the pylorospasm of ulcer, distant from the pylorus. It is of marked degree and is the most complete of any observed.

Increased tonus is observed less frequently than diminished tonus; it is seen in irritative conditions of the vagus, as part of the picture in

12. Rogers and Hardt: Am. Jour. Physiol., 1915, **38**, 274.

13. Alvarez, W. C.: Am. Jour. Physiol., 1916, **40**, 585.

14. Keith: Quoted from Alvarez; see Footnote 13.

15. Wilensky and Crohn: Am. Jour. Med. Sc., 1917, to be published.

16. After grave lesions the curve of tonicity remains constantly depressed and the wave of contraction is distinctly periodic. ("Après des graves lésions, la ligne de tonicité se maintient constamment très déprimé et la fonction motrice est nettement périodique." Arch. ital de biol., 1897, **27**, 61.)

17. Denechau: Paris Thesis, 1907.

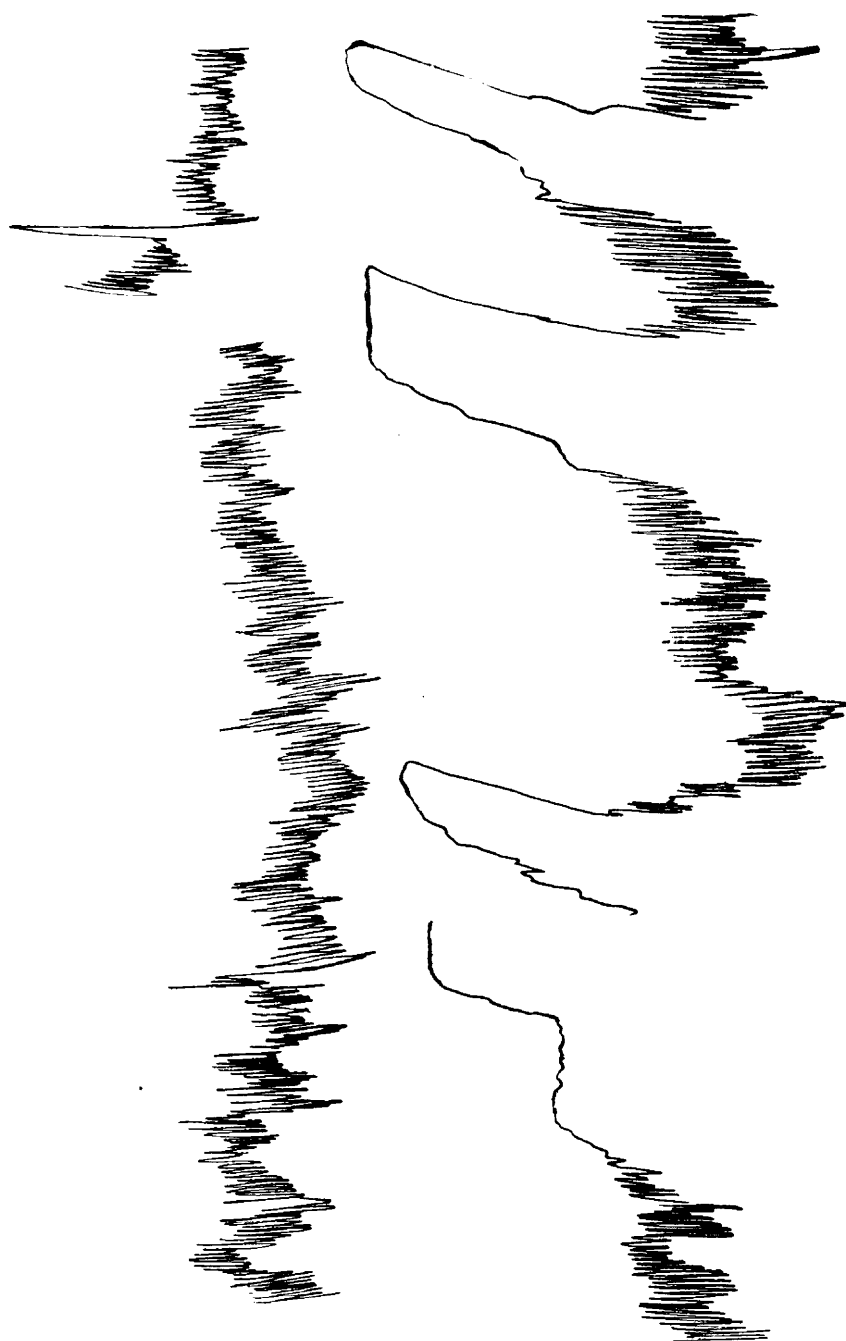


Fig. 10.—Malignant pyloric obstruction. Many of the hunger contractions are sustained and represent tetanic contractions of the empty viscus. (Control curve not given.)

tabes with gastric crises, and in the early stages of mechanical pyloric obstruction. In a case of carcinoma ventriculi, with infiltration of the mucosa with neoplastic tissue, increased tonus was observed, though no pyloric involvement occurred. This was due to rigidity of the wall of the viscus as well as to actual diminution of the interior space of the organ, the stomach assuming the appearance radiographically typical of a "leather-bottle" stomach.

*Hunger Contractions.*—In discussing the appearance of hunger contractions on our kymographic records, while we must agree with both Cannon and Carlson that hunger contractions are evidence of normality in the stomach, yet exceptions do occur, for we have observed the maintenance of good hunger contractions in cases in which gastric or duodenal ulcer was demonstrated at operation. Exceptions occur, however, in a small number of instances; as a rule, patients from whom a tracing has been obtained in which good and frequent hunger contractions occur, have proved at exploratory operation to be devoid of an organic lesion.<sup>18</sup>

The hunger contractions do not usually appear for the first few minutes of the observation, but once established, they follow each other in regular rhythm, separated by an interval which varies in each person, being in some ten to fifteen seconds; in others as long as sixty seconds apart. Sporadic or isolated contractions are less significant. The height of the contraction also varies, depending on the tonicity of the organ, being from 10 to 30 or 40 mm. Hg. Contractions of the nature of hunger contractions, of less than 10 mm. Hg. are really to be regarded as slightly exaggerated tonus waves, and represent the transition between tonus and hunger contractions.

Absence of hunger contractions is noted in atony, primary or secondary, and in organic lesions of the stomach and duodenum, particularly in ulcer. Carlson<sup>19</sup> observed diminution of tonic contractions in dogs in which the vagi had been severed.

Exaggeration of hunger contractions has been noted in conditions of vagus excitation. May<sup>20</sup> noted contractions three times the normal height on stimulating the vagus.

In pyloric stenosis we have noted that the nature of the contraction may be changed so that the summit of the contraction curve instead of being sharp or acuminate, with the fall of pressure sudden and immediately following the fastigium, is rounded or sustained as a plateau. Such a sustained elevation may endure for one, two or three minutes and represents a tonic spasm or tetany of the gastric musculature. It

18. Wilensky and Crohn: Tr. Am. Gastro-Enterol. Assn., 1916.

19. Carlson, A. J.: Am. Jour. Physiol., 1913 **32**.

20. May: Jour. Physiol., 1904, **31**, 260.

is pathognomonic, and was observed in two cases in which visible abdominal peristalsis was also evident. A similar condition was observed by Sick<sup>7</sup> and by Carlson and Ginsburg<sup>21</sup> in children with mechanical obstruction at the outlet of the viscus.

The case of tabes with gastric crises represents all phases of tonus from atony to hypertonicity, but is characterized by a complete absence of uniformity and by the occurrence of constant and unsystematized variations. The stomach seems to be in the same condition of ataxia as are the extremities, the bladder and the rectum.

A comparison between our interpretation of the kymographic tracings and the results of the Roentgen-ray examinations shows a fair degree of similarity. The most striking point is that good tonus con-

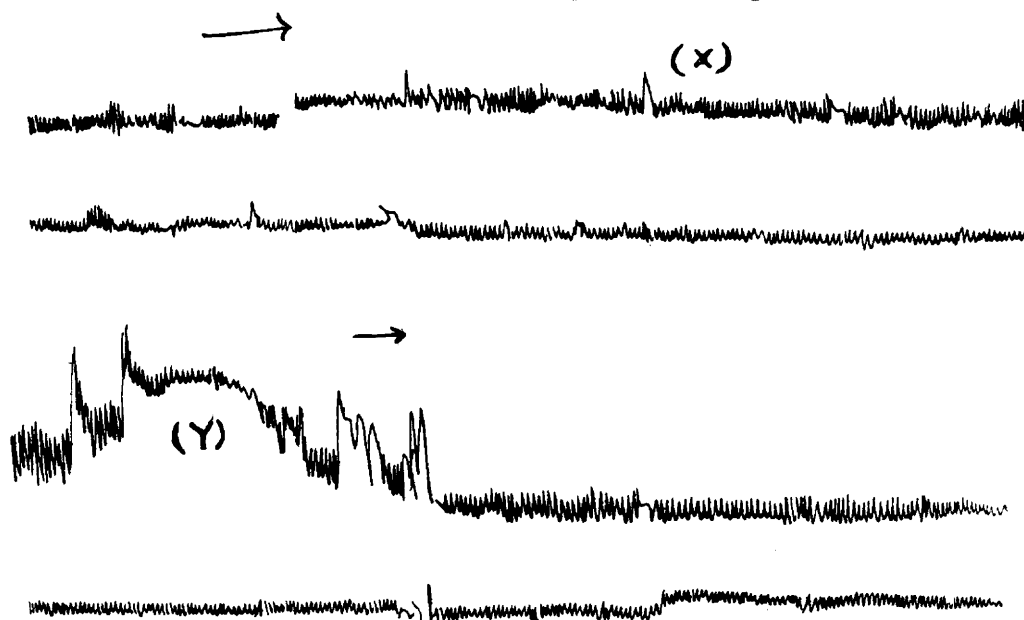


Fig. 11.—Tracing from a case of tabes with gastric crises. All phases are seen, from complete atony in the first few minutes to hyperatony, and even a sustained tetanic contraction as observed at (Y). The latter is often immediately followed by a long period of atony. Duration of observation, one-half hour.

tractions on the tracings signify good motility and normal emptying time of the stomach. No relationship exists between the tonus and hunger contractions demonstrated in the kymographic tracings, and the digestive peristalsis seen under the fluoroscope. As a rule, the tone of the stomach in the fasting state gives no indication of the degree of activity during digestion, and a state of atony in the fasting stomach

21. Carlson and Ginsburg: *Am. Jour. Physiol.*, 1915, **39**, 310.

may, under the stimulus of active digestion (barium-zoolak mixture), give place to fair, or active, or even hyperactive peristalsis. On the other hand, a complete absence of tonus contractions in one of the cases studies, corresponded with a complete absence of digestive peristalsis as seen under the fluoroscopic screen.

It has become evident from the data which we have collected to date, that hunger contractions and digestive peristaltic contractions are not identical. In fact, in Boldyreff's<sup>8</sup> experimental studies on dogs, a disappearance of hunger contractions after the introduction of food into the stomach was clearly demonstrated.

#### SUMMARY

We may summarize our findings under the following captions:

1. The human fasting stomach, into which has been introduced an inflated balloon connected at its distal end with a registering tambour, gives, normally, evidence of periodic variations of tone, at the usual rate of three to four waves per minute. Hunger contractions of greater amplitude, and caused by more rapid increases in intragastric pressure, occur singly or in groups.

2. The appearance of these two types of waves characterizes a normal stomach.

3. No disturbance was noted in purely secretory or other functional gastric disturbances.

4. The occurrence of atony of the stomach, both primary and secondary, is marked by the disappearance of hunger contractions, and when advanced, also of the tonal waves.

5. Organic disease of the stomach, including ulcer and carcinoma, disturbs the motor function of the stomach, frequently causing a disappearance of the normally existing hunger contractions. In gastric or duodenal ulcer the normal tonal variations may be maintained, but usually are disturbed, one or both elements disappearing.

6. In pyloric stenosis, either benign or malignant, the tonus is at first markedly increased, the occurrence of gastric tetanic contractions often being observed. As the stenosis progresses, the features of secondary atony of the gastric musculature may supervene.

7. Tabes, with gastric crises, gives evidence of complete incoordination of the neuromuscular control of the organ.

8. There is little or no correspondence between the tonal and the hunger contractions of the fasting stomach and the digestive peristalsis of the viscus after a meal.

9. The method utilized in these experiments is a physiologic one, well adapted to a study of the variations in the functional capacity of the gastric musculature in health and disease. It is not, primarily, a means for diagnosis.