The entire process of deglutition, therefore, occupies about six seconds.

The muscular movements which take place during all the periods of deglutition are peculiar. The first act is generally automatic, but it is under the control of the will. The second act is involuntary when once begun, but it may be excited by the voluntary passage of solids or liquids beyond the velum pendulum palati. It is impossible to perform the second act of deglutition unless there be some article, either solid or liquid, in the pharynx. It is easy to make three or four successful efforts consecutively, in which there is elevation of the larynx, with all the other characteristic movements; but a little attention will show that with each act a small quantity of saliva is swallowed. When the efforts have been frequently repeated, the movements become impossible, until time enough has elapsed between them for the saliva to collect.

All the movements of deglutition, except those of the first period, must be regarded as reflex, depending upon an impression made upon the afferent nerves distributed to the mucous membrane of the pharynx and œsophagus.

The position of the body has little to do with the facility with which deglutition is effected. Liquids or solids may be swallowed indifferently in all postures. Bérard saw a juggler pass an entire bottle of wine from the mouth to the stomach, while standing on his head. The same feat was accomplished with apparent ease, by a juggler who drank three glasses of beer while standing on his hands in the inverted posture (Flint).

Deglutition of Air.—In his essay on the mechanism of vomiting, Magendie stated that as soon as nausea occurred the stomach began to fill with air, so that before vomiting occurred, the organ became tripled in size. Magendie showed, fathermore, that the air entered the stomach by the œsophagus, for the distention occurred when the pylorus was ligated. In a subsequent memoir, the question of the deglutition of air, aside from the small quantity which is incorporated with the food during mastication and insalivation, was farther investigated. It was found that some persons had the faculty of swallowing air, and by practice, Magendie himself was able to acquire it, although it occasioned such distress that it was discontinued. Out of a hundred students of medicine, eight or ten were found able to swallow air.

It is not very uncommon to find persons who have gradually acquired the habit of swallowing air, in order to relieve uncomfortable sensations in the stomach; and when confirmed, it occasions persistent disorder in digestion. Quite a number of cases of this kind were reported by Magendie, and in several it was carried to such an extent as to produce great distention of the abdomen. A curious case of habitual air-swallowing was observed by the late Dr. Austin Flint and is reported in his work on the Practice of Medicine.

CHAPTER VIII.

GASTRIC DIGESTION.

Physiological anatomy of the stomach—Glands of the stomach—Closed follicles—Gastric juice—Gastric fistula in the human subject in the case of St. Martin—Secretion of the gastric juice—Properties and composition of gastric juice—Action of the gastric juice in digestion—Peptones—Action of the gastric juice upon fats, sugars and amylaceous substances—Duration of gastric digestion—Conditions which influence gastric digestion—Movements of the stomach.

Physiological Anatomy of the Stomach.

The stomach serves the double purpose of a receptacle for the food and an organ in which certain important digestive processes take place. It is situated in the upper part of the abdominal cavity and is held in place by folds of the peritoneum and by the œsophagus. Its form is not easily described. It has been compared to a bagpipe, which it resembles somewhat, when moderately distended. When empty, it is flattened, and in many parts its opposite walls are in contact. When moderately distended, its length is thirteen to fifteen inches (33 to 38 centimetres), its greatest diameter, about five inches (12·7 centimetres), and its capacity, one hundred and seventy-five cubic inches (2,868 c. c.), or about five pints. The parts usually noted in anatomical descriptions are the following: a greater and a lesser curvature; a greater and a lesser pouch; a cardiac, or œsophageal opening; a pyloric opening, which leads to the intestinal canal. The great pouch is sometimes called the fundus.

The coats of the stomach are three in number; the peritoneal, muscular and mucous. By some anatomists the fibrous tissue which unites the mucous to the muscular coat is regarded as a distinct covering and is called the fibrous coat.

Peritoneal Coat.—This is simply a layer of peritoneum, similar in structure to the membrane which covers the other abdominal viscera. It is a reflection of the membrane which lines the general abdominal cavity, which, on the viscera, is somewhat thinner than it is on the walls of the cavity. Over the stomach the peritoneum is $\frac{1}{300}$ to $\frac{1}{200}$ of an inch (83 to 125 μ) in thickness. It is a serous membrane and consists of ordinary fibrous tissue with a considerable number of elastic fibres. It is closely adherent to the subjacent muscular coat and is not very abundantly supplied with blood-vessels and nerves. Lymphatics have been demonstrated only in the subserous structure. The surface of the peritoneum is everywhere covered with regularly polygonal cells of pavement endothelium, closely adherent to each other and presenting a perfectly smooth surface which is moistened with a small quantity of liquid. An important office of this membrane is to present a smooth surface covering the abdominal parietes and viscera, so as to allow free movements of the organs over each other and against the walls of the abdomen.

Muscular Coat.—Throughout the alimentary canal, from the cardiac opening of the stomach to the anus, the muscular fibres forming the middle coat are of the non-striated variety. These fibres, called sometimes muscu-

lar fibre-cells, are very pale, with faint outlines, fusiform or spindle-shaped, and contain each an oval, longitudinal nucleus. They are closely adherent by their sides, and are so arranged as to dovetail into each other, forming sheets of greater or less thickness, depending upon the number of their layers. The muscular coat of the stomach varies in thickness in different animals. In the human subject, it is thickest in the region of the pylorus and is thinnest at the fundus. Its average thickness is about $\frac{1}{25}$ of an inch (1 mm.). In the pylorus its thickness is $\frac{1}{16}$ to $\frac{1}{12}$ of an inch (1·6 to 2·1 mm.), and in the fundus, $\frac{1}{50}$ to $\frac{1}{36}$ of an inch (0·5 to 0·7 mm.).

The muscular fibres exist in the stomach in two principal layers; an external longitudinal layer and an internal circular layer, with a third layer of oblique fibres extending over the great pouch only, which is internal to the circular layer. The longitudinal fibres are continued from the œsophagus and are most marked over the lesser curvature. They are not continued very distinctly over the rest of the stomach. The circular and oblique fibres are best seen with the organ everted and the mucous membrane carefully removed. The circular layer is not very distinct to the left of the cardiac opening, over the great pouch. Toward the pylorus, the layers of fibres are thicker, and at the opening into the duodenum, they form a powerful muscular ring, which is sometimes called the sphincter of the pylorus, or the pyloric muscle. At this point they project considerably into the interior of the organ and cease abruptly at the opening into the duodenum, so as to form a sort of valve, presenting, when contracted, a flat surface looking toward the

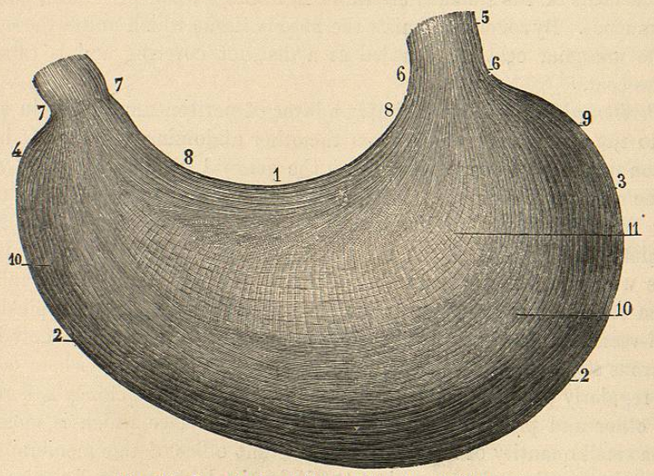

Fig. 57.—*Longitudinal fibres of the stomach* (Sappey).

1, lesser curvature; 2, 2, greater curvature; 3, greater pouch; 4, lesser pouch; 5, 6, 6, lower end of the œsophagus; 7, 7, pylorus; 8, 8, longitudinal fibres at the lesser curvature; 9, fibres extending over the greater curvature; 10, 10, a very thin layer of longitudinal fibres over the anterior surface of the stomach; 11, circular fibres seen through the thin layer of longitudinal fibres.

intestine. The oblique layer takes the place, in great part, of the circular fibres, over the great pouch. It extends obliquely over the fundus from left

to right and ceases at a distinct line extending from the left margin of the œsophagus to about the junction of the middle with the last third of the great curvature. At about the line where the oblique layer of fibres ceases the stomach becomes constricted during the movements which are incident to digestion, dividing the organ into tolerably distinct compartments.

The blood-vessels of the muscular coat are quite abundant and are arranged in a peculiar, rectangular net-work, which they always present in the non-

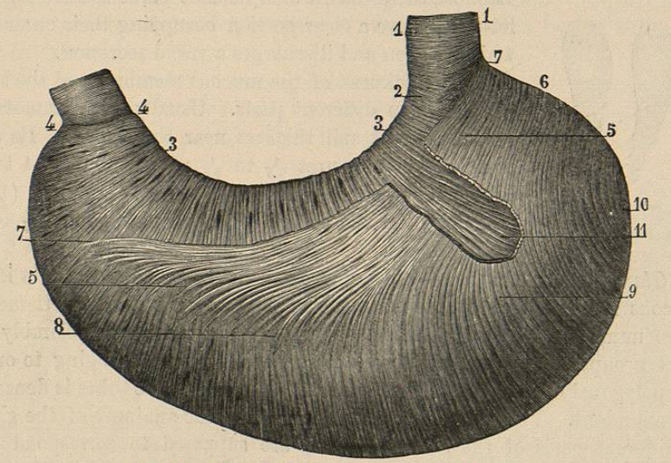

Fig. 58.—*Fibres seen with the stomach everted* (Sappey).

1, 1, œsophagus; 2, circular fibres at the œsophageal opening; 3, 3, circular fibres at the lesser curvature; 4, 4, circular fibres at the pylorus; 5, 5, 6, 7, 8, oblique fibres; 9, 10, fibres of this layer covering the greater pouch; 11, portion of the stomach from which these fibres have been removed to show the subjacent circular fibres.

striated muscular tissue. The nerves come from the pneumogastrics and the sympathetic system and are demonstrated with difficulty.

Mucous Coat.—The mucous membrane of the stomach is soft and velvety in appearance and of a reddish-gray color. It is loosely attached to the submucous muscular tissue and is thrown into large, longitudinal folds, which become effaced as the organ is distended. If the mucous membrane be stretched or if the stomach be everted and distended and the mucus be gently removed under a stream of water, the membrane will be found marked with polygonal pits or depressions, enclosed by ridges, which, in some parts of the organ, are quite regular. These are best seen with

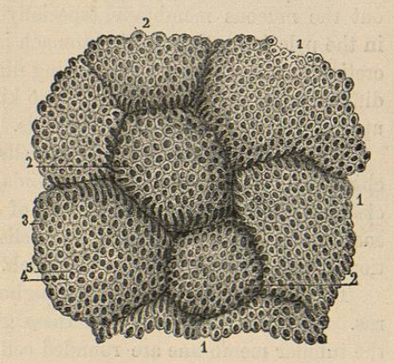

Fig. 59.—*Pits in the mucous membrane of the stomach, and orifices of the glands; magnified 20 diameters* (Sappey).

1, 1, 1, 2, 2, 2, 3, pits of different sizes; 4, 5, orifices of the gastric glands.

the aid of a simple lens, as many of them are quite small. The diameter of the pits is very variable, but the average is about $\frac{1}{200}$ of an inch (0·125 mm.). This appearance is not distinct toward the pylorus; the membrane here presenting irregular, conical projections and well marked villi resembling those found in the small intestine. The surface of the mucous membrane is covered with columnar or prismoidal epithelium, the cells being tolerably regular in shape, each with a clear nucleus and a distinct nucleolus. According to Landois, these cells, which he calls "mucus-secreting goblet-cells," have a clear portion occupying their outer half, which is open and discharges a viscid secretion.

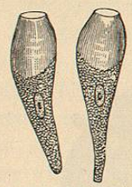

FIG. 60.—*Goblet-cells from the stomach* (Landois).

The thickness of the mucous membrane of the stomach varies in different parts. Usually it is thinnest near the œsophagus and thickest near the pylorus. Its thinnest portion measures $\frac{1}{75}$ to $\frac{1}{50}$ of an inch (0·34 to 0·5 mm.); its thickest portion, $\frac{1}{16}$ to $\frac{1}{12}$ of an inch (1·6 to 2·1 mm.), and the intermediate portion, about $\frac{1}{25}$ of an inch (1 mm.).

Glands of the Stomach.—Extending from the bottoms of the pits in the mucous membrane of the stomach to the submucous connective tissue, are large numbers of glands. These generally are arranged in tolerably distinct groups, surrounded by fibrous tissue, each group belonging to one of the polygonal depressions. The tissue which connects the tubes is dense but not abundant. There are marked differences in the anatomy of the glands in different parts of the stomach, which are supposed to correspond with differences in the uses of various parts of the mucous membrane. There are, indeed, two distinct varieties of glands; the peptic glands, which secrete pepsine, or an organic substance that is readily changed into pepsine, and the acid-glands, which are supposed to secrete free hydrochloric acid. The peptic glands are most abundant in the pyloric portion of the stomach and around the cardiac opening. The so-called acid-glands are found throughout the mucous membrane, especially in the greater pouch. The secretion in the pyloric portion of the stomach is not acid at any time, while the secretion in the greater pouch, during digestion, is always strongly acid. The difference in the action of these two kinds of glands is supposed to depend upon differences in the secreting cells.

The pyloric glands are lined by cells which may be called peptic cells (the chief-cells of German writers), conoidal or cuboidal in form, and relatively clear, especially during the intervals of digestion. Similar cells are found, in connection with the so-called acid-cells (parietal cells) in the secreting portion of the glands of the greater pouch.

The acid-glands are found throughout the stomach, except near the pylorus. The secreting portion of these glands contains peptic cells, but near the tubular membrane are rounded cells, larger than the peptic cells, darker and more granular, which are the acid, or parietal cells. These are strongly stained when treated with osmic acid (Nussbaum). It is probable that the so-called acid-glands secrete pepsine as well as an acid, while the pyloric

glands secrete pepsine but no acid. According to the views just stated, in the glands of the greater pouch, the acid is secreted by the rounded acid-cells while the pepsine is secreted by cells (peptic cells) similar to those which line the secreting portion of the pyloric glands. During the intervals of digestion, pepsine is in process of formation by the peptic cells, and no acid is produced; but acid begins to be secreted soon after food is received into the stomach. It is now thought that the peptic cells do not produce pepsine directly, but a substance sometimes called zymogen, but more properly propepsine or pepsinogen, which is changed into true pepsine by the action of hydrochloric acid.

There is some confusion among writers with regard to the names of the different kinds of secreting cells of the stomach, the acid-cells being frequently described as "peptic cells." It seems proper, however, to call the

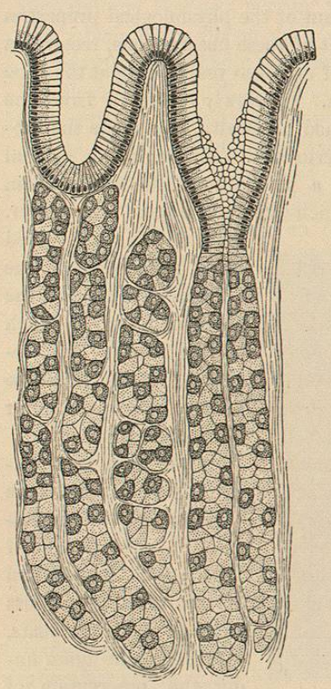

FIG. 61.—*Glands of the greater pouch of the stomach* (Heidenhain).

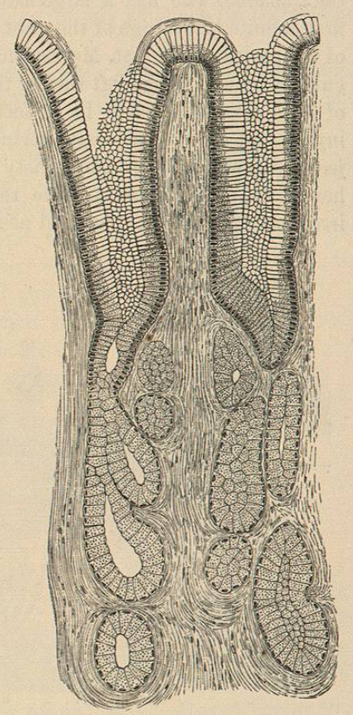

FIG. 62.—*Pyloric glands* (Ebstein).

cells which produce pepsine, peptic cells, and the cells that are supposed to produce acid, acid-cells.

The glands of the stomach have an excretory portion and a secreting portion, the latter presenting several branches. The excretory portion is lined by cells like those found on the surface of the mucous membrane.

The secreting portion is lined by the peptic and the acid-cells already described. In Fig. 61 the darker cells are the acid-cells, and the lighter cells, the peptic cells. In Fig. 62 the secreting portion contains peptic cells only.

Closed Follicles.—In the substance of the mucous membrane, between the tubes and near their cæcal extremities, are occasionally found closed follicles, like the solitary glands and patches of Peyer of the intestines. These are not always present in the adult but are generally found in children. They are usually most abundant over the greater curvature, though they may be found in other situations. In their anatomy they are identical with the closed follicles of the intestines, and they do not demand special consideration in this connection.

Gastric Juice.—The observations of Beaumont upon Alexis St. Martin, the Canadian who had a large fistulous opening into the stomach, gave the first definite knowledge of the most important of the physiological properties of the gastric juice. St. Martin, the subject of these observations, received a gunshot wound in the left side, at the age of eighteen years, being at the time of good constitution and in perfect health. He slowly recovered from the injury, and after three years, having regained his health, was made the subject of a great number and variety of experiments. Although the general health had been restored, there remained a perforation into the stomach, irregularly circular in form and nearly an inch (2·5 centimetres) in diameter. This opening was closed by a protrusion of the mucous membrane in the form of a valve, which could readily be depressed by the finger so as to expose the interior of the stomach.

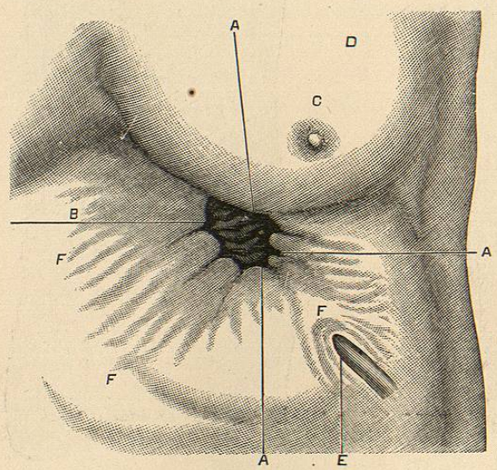

FIG. 63.—*Gastric fistula in the case of St. Martin* (Beaumont).
A, A, A, B, borders of the opening into the stomach: C, left nipple; D, chest; E, cicatrices from the wound made for the removal of a piece of cartilage; F, F, F, cicatrices of the original wound.

From May, 1825, until August of the same year, St. Martin was under the observation of Beaumont. At the end of that time he was lost sight of for four years. He then came again under the observation of Beaumont and continued in his service, doing the work of a servant, until March, 1831. After this he was under observation from time to time until 1836, always enjoying perfect health, with good digestion. The last published observations made upon this case were in 1856.

The following was the method employed by Beaumont in extracting the gastric juice: The subject was placed on the right side in the recumbent posture, the valve was depressed within the aperture, and a gum-elastic tube, of the size of a large quill, was passed into the stomach to the extent of five to six inches (12 to 15 centimetres). On turning him upon the left side until the opening became dependent, the stimulation of the tube caused the secretion to flow, sometimes in drops and sometimes in a small stream.

Since the publication of Beaumont's experiments, many observations have been made upon animals in which a permanent gastric fistula had been established. In these experiments the dog is most frequently used, as in this animal the operation usually is successful. The animals operated upon by Bassow, who was the first to establish a gastric fistula (1842), were merely objects of curiosity; but Blondlot (1843) and others fixed a tube in the stomach, collected the juice and made important observations with regard to its action in digestion. Most experimenters follow the method employed by Blondlot and Bernard, making the opening in the abdomen in the median line, a little below the ensiform cartilage.

Having established a permanent fistula into the stomach, after the wound has cicatrized around the canula, the animal suffers no inconvenience and may serve indefinitely for experiments on the gastric juice. In some experiments, the flow of gastric juice has been excited by the introduction into the stomach, of pieces of tendon or hard, indigestible articles, on the ground that the fluid taken from the fistula, under these conditions, is unmixed with the products of gastric digestion; but it has been shown that the quantity and character of the secretion are influenced by the nature of the stimulus, and it is proper, therefore, to excite the action of the stomach by articles which are relished by the animal. For this purpose, lean meat may be given, cut into pieces so small that they will be swallowed entire, and first thrown into boiling water so that their exterior may become somewhat hardened. The cork is then removed from the tube, which is freed from mucus etc., when the gastric juice will begin to flow, sometimes immediately and sometimes in four or five minutes after the food has been taken. It flows in clear drops or in a small stream for about fifteen minutes, nearly free from the products of digestion. At the end of this time it is generally accompanied with grumous matter, and the experiment should be concluded if it be desired simply to obtain the pure secretion. In fifteen minutes, two to three ounces (60 to 90 c.c.) of fluid may be obtained from a good-sized dog, which, when filtered, is perfectly clear; and this operation may be repeated three or four times a

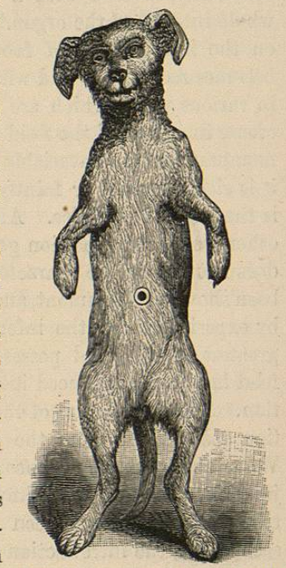

FIG. 64.—*Dog with a gastric fistula* (Béclard).

week without interfering with the character of the secretion or injuring the health of the animal.

Although instances of gastric fistula in the human subject had been reported before the case of St. Martin and have been observed since that time, the remarkably healthy condition of the subject and the extended experiments of Beaumont have rendered this case memorable in the history of physiology. This is the only instance on record, in which pure, normal gastric juice has been obtained from the human subject; and it has served as the standard for comparison for subsequent experiments on the inferior animals.

Artificial gastric juice, prepared by extracting the active principle from the mucous membrane of the stomach of different animals and adding hydrochloric acid, is useful in observations with regard to the chemistry of the peculiar ferment, but fluids prepared in this way are not absolutely identical with the natural secretion. Extracts of the mucous membrane were made by Eberle (1834), Von Wittich, Brücke and many others.

Secretion of the Gastric Juice.—According to Beaumont, during the intervals of digestion, the mucous membrane is comparatively pale, "and is constantly covered with a very thin, transparent, viscid mucus, lining the whole interior of the organ." On the application of any irritation, or better, on the introduction of food, the membrane changes its appearance. It becomes red and turgid with blood; small pellucid points begin to appear in various parts, which are drops of gastric juice; and these gradually increase in size until the fluid trickles down the sides in small streams. The membrane is now invariably of a strongly acid reaction, while at other times it is either neutral or faintly alkaline. The thin, watery fluid thus produced is the true gastric juice. Although the stomach may contain a clear fluid at other times, this secretion generally is abnormal. It is but slightly acid and does not possess the characteristic properties of the natural secretion. It has been shown by Beaumont, and his observations have been repeatedly confirmed by experiments on the inferior animals, that the gastric juice is secreted in greatest quantity and possesses the most powerful solvent properties, when food has been introduced into the stomach by the natural process of deglutition. The stimulation of the mucous membrane is then general, and secretion takes place from the entire surface capable of producing the fluid. When any foreign substance, as the gum-elastic tube used in collecting the juice, is introduced, the stimulation is local, and the flow of fluid is comparatively slight. It has been also observed that the quantity immediately secreted on the introduction of food, after a long fast, is always much greater than when food has been taken after the ordinary interval.

While natural food is undoubtedly the proper stimulus for the stomach, and while, in normal digestion, the quantity of gastric juice is perfectly adapted to the work it has to perform, it has been noted that savory and highly seasoned articles generally produce a more abundant secretion than those which are comparatively insipid. An abundant secretion is likewise excited by some of the vegetable bitters.

Impressions made on the nerves of gustation have a marked influence in exciting the action of the mucous membrane of the stomach. Blondlot found that sugar, introduced into the stomach of a dog by a fistula, produced a flow of juice much less abundant than when the same quantity was taken by the mouth. To convince himself that this did not depend upon the want of admixture with the alkaline saliva, he mixed the sugar with the saliva and passed it in by the fistula, when the same difference was observed. In some animals, particularly when they are very hungry, the sight and odor of food will excite secretion of gastric juice.

A febrile condition of the system, the depression resulting from an excess in eating and drinking, or even purely mental conditions, such as anger or fear, vitiate, diminish and sometimes entirely suppress secretion by the stomach. At some times, under these conditions, the mucous membrane becomes red and dry, and at others it is pale and moist. In the morbid conditions, drinks are immediately absorbed, but food remains undigested in the stomach for twenty-four to forty-eight hours (Beaumont).

After the food has been in part liquefied and absorbed and in part reduced to a pultaceous consistence, the secretion of gastric juice ceases; the movements of the stomach having gradually forced that portion of the food which is but partially acted upon in this organ or is digested only in the small intestines out at the pylorus. The stomach is thus entirely emptied, the mucous membrane becomes pale, and its reaction loses its marked, acid character, becoming neutral or faintly alkaline.

Quantity of Gastric Juice.—The *data* for determining the quantity of gastric juice secreted in the twenty-four hours are so uncertain that it seems impossible to fix upon any estimate that can be accepted even as an approximation. Still, the quantity must be considerable, in view of the large quantity of alimentary matter which is acted upon in gastric digestion. It is probably not less than six pounds (2·72 kilos.) or more than fourteen pounds (6·35 kilos.). After this fluid has performed its office in digestion, it is immediately reabsorbed, and but a small quantity of the secretion exists in the stomach at any one time.

Properties and Composition of Gastric Juice.—The gastric juice is mixed in the stomach with more or less mucus secreted by the lining membrane. When drawn by a fistula, it generally contains particles of food, which have become triturated and partially disintegrated in the mouth, and is always mixed with a certain quantity of saliva, which is swallowed during the intervals of digestion as well as when the stomach is active. By adopting certain precautions, however, the fluid may be obtained nearly free from impurities, except the admixture of saliva. The juice taken from the stomach during the first moments of its secretion, and separated from mucus and foreign matters by filtration, is a clear fluid, of a faint yellowish or amber tint and possessing little or no viscidity. Its reaction is always strongly acid; and it is now a well established fact that any fluid, secreted by the mucous membrane of the stomach, which is either alkaline or neutral, is not normal gastric juice.

The specific gravity of the gastric juice in the case of St. Martin, accord-