

contractions of the stomach upon the food contained in its cavity is to subject it to a tolerably uniform pressure in the cardiac portion, the general tendency of the movement being toward the pylorus, along the greater curvature, and back from the pylorus toward the great pouch, along the lesser curvature. At the constricted part which separates the cardiac from the pyloric portion, there is an obstruction to the passage of the food until it has been sufficiently acted upon by the secretions in the cardiac division to have become reduced to a pultaceous consistence. The alimentary mass then passes into the pyloric division, and by a more powerful contraction than occurs in other parts of the stomach, it is passed into the small intestine.

The revolutions of the alimentary mass, thus accomplished, take place slowly, by gentle and persistent contractions of the muscular coat; the food occupying two or three minutes in its passage entirely around the stomach. Every time that a revolution is accomplished, the contents of the stomach are somewhat diminished in quantity; probably, in a slight degree, from absorption of digested matter by the stomach itself, but chiefly by the gradual passage of the softened and disintegrated mass into the small intestine. This process continues until the stomach is emptied, lasting between two and four hours; after which, the movements of the stomach cease until food is again introduced.

Regurgitation of food by contractions of the muscular coats of the stomach, eructation, or the expulsion of gas, and vomiting are not physiological acts. It has been shown that vomiting is produced by contractions of the abdominal muscles and the diaphragm, compressing the stomach, which is passive, except that the pyloric opening is firmly closed, the cardiac opening being relaxed. Eructation, although usually involuntary, is sometimes under the control of the will. When it occurs, while it is difficult or impossible to prevent the discharge of the gas, the accompanying sound may be readily suppressed. Eructation frequently becomes a habit, which in many persons is so developed by practice that the act may be performed voluntarily at any time. The gaseous contents of the stomach during digestion are composed of oxygen, carbon dioxide, hydrogen and nitrogen, in proportions that are very variable.

CHAPTER IX.

INTESTINAL DIGESTION.

Physiological anatomy of the small intestine—Glands of Brunner—Intestinal tubules, or follicles of Lieberkühn—Intestinal villi—Solitary glands, or follicles, and patches of Peyer—Intestinal juice—Action of the intestinal juice in digestion—Pancreatic juice—Action of the pancreatic juice upon starches and sugars—Action upon nitrogenized substances—Action upon fats—Action of the bile in digestion—Biliary fistula—Variations in the flow of bile—Movements of the small intestine—Peristaltic and antiperistaltic movements—Uses of the gases in the small intestine—Physiological anatomy of the large intestine—Processes of fermentation in the intestinal canal—Contents of the large intestine—Composition of the faeces—Excretine and excretoleic acid—Stercorine—Indol, skatol, phenol etc.—Movements of the large intestine—Defecation—Gases found in the alimentary canal.

PHYSIOLOGICAL ANATOMY OF THE SMALL INTESTINE.

THE small intestine, extending from the pyloric extremity of the stomach to the ileo-cæcal valve, is loosely held to the spinal column by a double fold of serous membrane, called the mesentery. As the peritoneum which lines the cavity of the abdomen passes from either side to the spinal column, it comes together in a double fold just in front of the great vessels along the spine, and passing forward, it divides again into two layers, which become continuous with each other and enclose the intestine, forming its external coat. The width of the mesentery is usually three to four inches (7.62 to 10.16 centimetres); but at the beginning and at the termination of the small intestine, it suddenly becomes shorter, binding the duodenum and that portion of the intestine which opens into the caput coli closely to the subjacent parts. The mesentery thus keeps the intestine in place, but it allows a certain degree of motion, so that the tube may become convoluted, accommodating itself to the size and form of the abdominal cavity. The form of these convolutions is irregular and is continually changing. The length of the small intestine, according to Gray, is about twenty feet (6.1 metres); but the canal is very distensible, and its dimensions are subject to frequent variations. Its average diameter is about an inch and a quarter (3.18 centimetres).

The small intestine has been divided into three portions, which present anatomical and physiological peculiarities, more or less marked. These are the duodenum, the jejunum and the ileum.

The duodenum has received its name from the fact that it is about the length of the breadth of twelve fingers, or eight to ten inches (20.32 to 25.4 centimetres). This portion of the intestine is considerably wider than the constricted pyloric end of the stomach, with which it is continuous, and is also much wider than the jejunum.

The coats of the duodenum, like those of the other divisions of the intestinal tube, are three in number. The external is the serous, or peritoneal coat, which has already been described. The middle, or muscular coat is composed of non-striated muscular fibres, such as exist in the stomach, arranged in two layers. The external, longitudinal layer is not very thick, and the direction of its fibres can be made out easily only at the outer portions of the tube, opposite the attachment of the mesentery. Near the mesenteric border the outlines of the fibres are very faint. This is true throughout the

whole of the small intestine; although the fibres are most abundant in the duodenum. The internal layer of fibres is considerably thicker than the

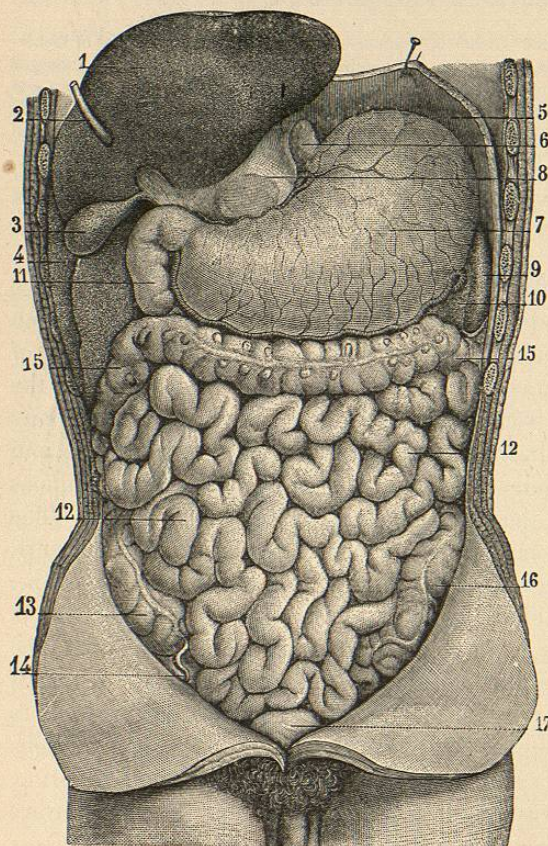


FIG. 66.—Stomach, liver, small intestine etc. (Sappey).
1, inferior surface of the liver; 2, round ligament of the liver; 3, gall-bladder; 4, superior surface of the right lobe of the liver; 5, diaphragm; 6, lower portion of the oesophagus; 7, stomach; 8, gastro-hepatic omentum; 9, spleen; 10, gastro-splenic omentum; 11, duodenum; 12, 12, small intestine; 13, cæcum; 14, appendix vermiformis; 15, 15, transverse colon; 16, sigmoid flexure of the colon; 17, urinary bladder.

what narrower and thinner than the jejunum, otherwise possessing no marked peculiarities except in its mucous membrane. This division of the intestine opens into the colon.

Mucous Membrane of the Small Intestine.—The mucous coat of the small intestine is somewhat thinner than the lining membrane of the stomach. It is thickest in the duodenum and gradually becomes thinner toward the ileum. It is highly vascular, presenting, like the mucous membrane of the stomach, a great increase in the quantity of blood during digestion. It has a peculiar soft and velvety appearance, and during digestion it is of a vivid-red color, being pale pink during the intervals. It presents for anatomical description the following parts: 1, folds of the membrane, called valvulæ conniventes; 2, duodenal racemose glands, or glands of Brunner; 3, intestinal

longitudinal layer. These fibres encircle the tube, running generally at right angles to the external layer, but some of them having rather an oblique direction. The circular layer is thickest in the duodenum, diminishing gradually in thickness to the middle of the jejunum, but afterward maintaining a nearly uniform thickness throughout the canal, to the ileo-cæcal valve.

The jejunum, the second division of the small intestine, is continuous with the duodenum. It presents no well marked line of separation from the third division, but is generally considered as including the upper two-fifths of the small intestine, the lower three-fifths being called the ileum. It has received the name jejunum from the fact that it is almost always found empty after death.

The ileum is some-

tubules, or follicles of Lieberkühn; 4, intestinal villi; 5, solitary glands, or follicles; 6, agminated glands, or patches of Peyer.

The valvulæ conniventes, simple transverse duplicatures of the mucous membrane of the intestine, are particularly well marked in man, although they are found in some of the inferior animals belonging to the class of mammals, as the elephant and the camel. They render the extent of the mucous membrane much greater than that of the other coats of the intestine. Beginning at about the middle of the duodenum, they extend, with no diminution in number, throughout the jejunum. In the ileum they progressively diminish in number, until they are lost at about its lower third. There are about six hundred of these folds in the first half of the small intestine and two hundred to two hundred and fifty in the lower half (Sappey). In those portions of intestine where they are most abundant, they increase the length of the mucous membrane to about double that of the tube itself; but in the ileum they do not increase the length more than one-sixth. The folds are always transverse and occupy usually one-third to one-half of the circumference of the tube, although a few may extend entirely around it. The greatest width of each fold is at its centre, where it measures a quarter to half an inch (6.4 to 12.7 mm.). From this point the width gradually diminishes until the folds are lost in the membrane as it is attached to the muscular coat. Between the folds are found fibres of connective tissue similar to those which attach the membrane throughout the whole of the alimentary tract. This, though loose, is constant, and it prevents the folds from being effaced, even when the intestine is distended to its utmost. Between the folds are also found blood-vessels, nerves and lymphatics.

The position and arrangement of the valvulæ conniventes are such that they move freely in both directions and may be applied to the inner surface of the intestine either above or below their lines of attachment. It is evident that the food, as it passes along in obedience to the peristaltic movements, must, by insinuating itself beneath the folds and passing over them, be exposed to a greater extent of mucous membrane than if these valves did not exist. This is about the only definite use that can be assigned to them.

Thickly set beneath the mucous membrane in the first half of the duodenum, and scattered here and there throughout the rest of its extent, are the duodenal racemose glands, or the glands of Brunner. These are not found in other parts of the intestinal canal. In their structure they closely resemble the racemose glands of the oesophagus. On

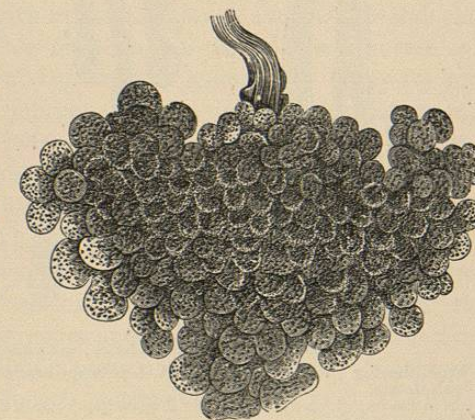


FIG. 67.—Gland of Brunner, from the human subject (Frey).

dissecting the muscular coat from the mucous membrane, they may be seen with the naked eye, in the areolar tissue, in the form of little, rounded bodies, about one-tenth of an inch (2.5 mm.) in diameter. Examined microscopically, these bodies are found to consist of a large number of rounded follicles held together by a few fibres of connective tissue. They have blood-vessels ramifying on their exterior and are lined with glandular epithelium. They communicate with an excretory duct which penetrates the mucous membrane and opens into the intestinal cavity. When these structures are examined in a perfectly fresh preparation, the excretory duct is frequently found to contain a clear, viscid mucus, of an alkaline reaction. This secretion has never been obtained in quantity sufficient to admit of the determination of its chemical or physiological properties. Its quantity must be very small, compared with the secretion produced by the follicles of Lieberkühn.

The intestinal tubules, or follicles of Lieberkühn, the most important glandular structures in the intestinal mucous membrane, are found through-

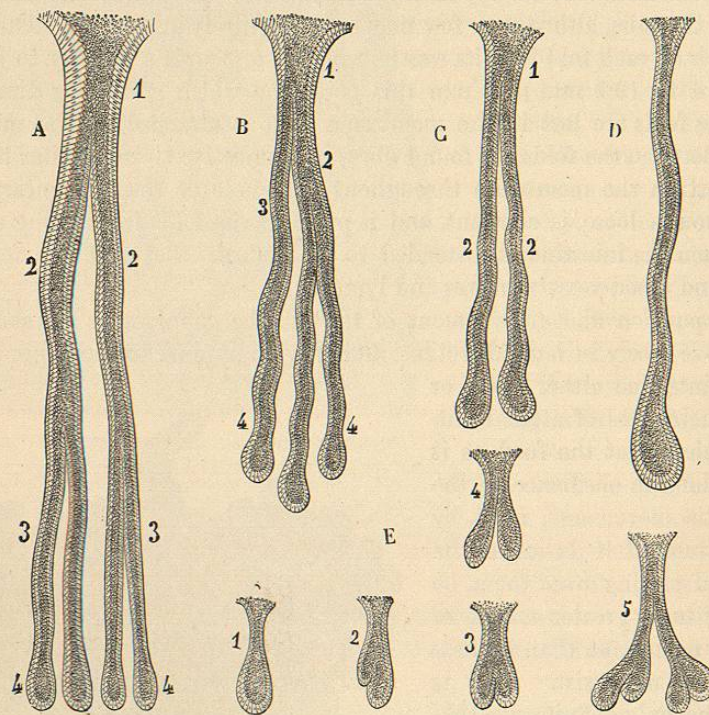


FIG. 68.—Intestinal tubules; magnified 100 diameters (Sappey).

- A. From the dog. 1, excretory canal; 2, 2, primary branches; 3, 3, secondary branches; 4, 4, terminal culs-de-sac.
 B. From the ox. 1, excretory canal; 2, principal branch dividing into two; 3, branch undivided; 4, 4, terminal culs-de-sac.
 C. From the sheep. 1, trunk; 2, 2, branches.
 D. Single tube, from the pig.
 E. From the rabbit and hare. 1, simple gland; 2, 3, 4, bifid glands; 5, compound gland from the duodenum.

out the whole of the small and large intestines. In examining a thin section of the mucous membrane, these little tubes are seen closely packed together,

occupying nearly the whole of its structure. Between the tubules, are blood-vessels, embedded in a dense stroma of fibrous tissue with non-striated muscular fibres. In vertical sections of the mucous membrane, the only situations where the tubules are not seen are in that portion of the duodenum occupied by the ducts of the glands of Brunner and immediately over the centre of the larger solitary glands and some of the closed follicles which are collected to form the patches of Peyer. The tubes are not entirely absent in the patches of Peyer, but are here collected in rings, twenty or thirty tubes deep, which surround each of the closed follicles. Microscopical examination of the surface of the mucous membrane by reflected light shows that the openings of the tubules are between the villi.

The tubules usually are simple, though sometimes bifurcated, are composed externally of a structureless basement-membrane, and are lined with a layer of cylindrical epithelium like the cells which cover the villi, the only difference being that in the tubes the cells are shorter. These cells never contain fatty granules, even during the digestion of fat. The central cavity which the cells enclose, which is about one-fourth of the diameter of the tube, is filled with a clear, viscid fluid, which is the most important constituent of the intestinal juice. The length of the tubules is equal to the thickness of the mucous membrane and is about $\frac{1}{3}$ of an inch (0.33 mm.). Their diameter is about $\frac{1}{360}$ of an inch (0.07 mm.). In man they are cylindrical, terminating in a single, rounded, blind extremity, which frequently is a little larger than the rest of the tube. These tubules are the chief agents concerned in the production of the fluid known as the intestinal juice.

The intestinal villi, though chiefly concerned in absorption, are most conveniently considered in this connection. These exist throughout the whole of the small intestine, but are not found beyond the ileo-cæcal valve, although they cover that portion of the valve which looks toward the ileum. Their number is very great, and they give to the membrane its peculiar and characteristic velvety appearance. They are found on the valvæ conniventes as well as on the general surface of the mucous membrane. They are most abundant in the duodenum and jejunum. Sappey estimated, as an average, about 6,450 to the square inch (1,000 in a square centimetre) and more than ten millions (10,125,000) throughout the whole of the small intestine. In the human subject the villi are flattened cylinders or cones. In the duodenum, where they resemble somewhat the elevations found in the pyloric portion of the stomach, they are shorter and broader than in other situations and are more like flattened, conical folds. In the jejunum and ileum they are in the form of long, flattened cones and cylinders. As a rule the cylindrical form predominates in the lower portion of the intestine. In the jejunum they attain their greatest length, measuring here $\frac{1}{30}$ to $\frac{1}{20}$ of an inch (0.83 to 1.25 mm.) in length by $\frac{1}{70}$ to $\frac{1}{120}$ of an inch (0.36 to 0.21 mm.) in breadth at their base.

The structure of the villi shows them to be simple elevations of the mucous membrane, provided with blood-vessels and with lacteals, or intestinal lymphatics. Externally is found a single layer of long, cylindrical epithelial

cells, resting on a structureless basement-membrane. These cells, though closely adherent to the subjacent parts during life, are easily detached after death and are almost always destroyed and removed in injected preparations. They adhere firmly to each other and are isolated with difficulty in microscopical preparations. The borders of the free surfaces of these cells are thickened and finely striated, forming, as it were, a special membrane covering the villus and external to the cells. Between the cylindrical cells are a few of the so-called goblet-cells similar to those found on the mucous membrane of the stomach (see Fig. 60, page 214).

FIG. 69.—Intestinal villus (Leydig).

a, a, a, epithelial covering; b, b, capillary net-work; c, c, longitudinal muscular fibres; d, lacteal.

FIG. 70.—Capillary net-work of an intestinal villus (Frey).

a, venous trunk; b, arterial trunk.

The substance of the villus is composed of amorphous matter, in which are embedded nuclei and a few fibres, fibro-plastic cells and non-striated muscular fibres. The blood-vessels are very abundant; four or five, and sometimes as many as twelve or fifteen arterioles entering at the base, ramifying through the substance of the villus, but not branching or anastomosing or even diminishing in caliber until, by a slightly wavy turn or loop, they communicate with the venous radicles, each of which is somewhat larger than the arterioles. The veins all converge to two or three branches, finally emptying into a large trunk situated nearly in the long axis of the villus.

The muscular fibres of the villi are longitudinal, forming a thin layer surrounding the villus, about half-way between the periphery and the centre, and continuous with the muscular coat of the intestine.

In the central portion of each villus, is a small lacteal, one of the vessels of origin of the lacteal system, with an extremely delicate wall composed of endothelial cells with frequent stomata, or small openings, between their

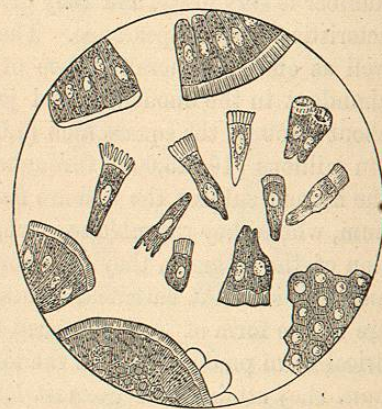


FIG. 71.—Epithelium of the small intestine of the rabbit (Funke).

borders. This vessel is probably in the form of a single tube, either simple or presenting a few short, rounded diverticula.

The stomata of the lacteal vessel are thought to communicate with lymph-spaces or canals in the substance of the villus. Owing to the excessive tenuity of the walls of the lacteals in the villi, it has been found impossible to fill these vessels with an artificial injection, although the lymphatics subjacent to them may be easily distended and studied in this way.

No satisfactory account has ever been given of nerves in the intestinal villi. If any exist in these structures, they probably are derived from the sympathetic system.

The solitary glands, or follicles, and the patches of Peyer, or agminated glands, have one and the same structure, the only difference being that those called solitary are scattered singly in very variable numbers throughout the small and large intestine, while the agminated glands consist of these follicles collected into patches of different sizes. These patches are generally found in the ileum. The number of the solitary glands is very variable, and they are sometimes absent. The patches of Peyer are always situated in that portion of the intestine opposite the attachment of the mesentery. They are likewise variable in number and are irregular in size. They usually are irregularly oval in form, and measure half an inch to an inch and a half (12.7 to 38.1 mm.), in length by three-fourths of an inch (19.1 mm.) in breadth. Sometimes they are three to four inches (7.6 to 10.1 centimetres) long, but the largest are always found in the lower part of the ileum. Their number is about twenty, and they are generally confined to the ileum; but when they are very abundant—for they sometimes exist to the number of sixty or eighty—they may be found in the jejunum or even in the duodenum.

Two varieties of the patches of Peyer have been described by anatomists. In one of these varieties, the patch is quite prominent, its surface being slightly raised above the general mucous surface; in the other, the surface is smooth, and the patch is distinguished at first with some difficulty. The more prominent patches are covered with mucous membrane arranged in folds something like the convolutions on the surface of the brain. The valvulae conniventes cease at or very near their borders. These are the only patches which are generally described as the glands of Peyer, the others, which may be called the smooth patches, being frequently overlooked. The latter are covered with a smooth, thin, and closely adherent mucous membrane. Their follicles are small and abundant. The borders of these patches are much less strongly marked than in those of the first variety. As they are evident only upon close examination and as they are the only patches present in certain individuals, it is said that sometimes the patches of Peyer are wanting. They are usually in less number than the first variety.

The villi are very large and prominent on the mucous membrane covering the first variety of Peyer's patches, especially at the summit of the folds. In the second variety the villi are the same as over other parts of the mu-

