ANATOMY OF THE STOMACH AND DUODENUM

ANATOMY OF THE STOMACH

GENERAL CONSIDERATIONS

The stomach, as a J-shaped dilation of the alimentary canal, is continuous with the esophagus proximally and the duodenum distally. It functions primarily as a reservoir to store large quantities of recently ingested food, thus allowing intermittent feedings, initiating the digestive process, and releasing its contents in a controlled fashion downstream to accommodate the much smaller capacity of the duodenum. The stomach volume ranges from about 30 mL in a neonate to 1.5 to 2 L in adulthood.

The stomach is recognizable in the fourth week of gestation as a dilation of the distal foregut (Fig. 45-1). As the stomach enlarges, the dorsal aspect grows more rapidly than the ventral aspect, thus forming the greater curvature. Additionally, during the enlargement process, the stomach rotates 90 degrees around its longitudinal axis, orienting the greater curvature (the dorsal aspect) to the left and the lesser curvature (ventral aspect) to the right. The combined effects of rotation and ongoing differential growth result in the stomach lying transversely in the mid and left upper abdomen. The events also explain the vagal innervation of the stomach: the right vagus nerve innervating the posterior stomach wall (the primordial right side) and the left vagus nerve innervating the anterior wall (the primordial left side).
The final location of the stomach is variable owing in part to its two-point fixation at the gastroesophageal and gastroduodenal junctions, allowing for considerable mobility. The
gastroesophageal junction generally lies to the left of the 10th thoracic vertebral body, 1 to 2 cm below the diaphragmatic hiatus. The gastroduodenal junction lies at L1 and generally to the right of the midline in the recumbent fasted individual. The gastroduodenal junction of a distended upright adult may be considerably lower. The left-sided and caudal greater curvature may extend below the umbilicus depending on the degree of distention, position, and gastric peristaltic phase.

The greater curvature forms the left lower stomach border, whereas the lesser curvature forms the right upper border. Posteriorly, portions of the pancreas, transverse colon, diaphragm, spleen, and apex of the left kidney and adrenal gland bound the stomach. The posterior wall of the stomach actually comprises the anterior wall of the omental bursa, or lesser peritoneal sac. Anteriorly, the liver bounds the stomach, whereas the inner aspect of the anterior abdominal wall bounds the anterior left lower aspect.

The stomach is completely invested by peritoneum, except for a small bare area at the gastroesophageal junction. This peritoneum passes as a double layer from the lesser curvature to the liver as the gastrohepatic portion of the lesser omentum and then hangs down from the fundus and greater curvature as the greater omentum, extending to the transverse colon (as the gastrocolic ligament), spleen (as the gastrosplenic ligament), and diaphragm (as the gastrophrenic ligament).

The stomach is divided into four regions, which can be defined by anatomic or histologic landmarks (Fig. 45-2).\(^2\) Anatomically, the cardia is a small, ill-defined area of the stomach immediately adjacent to its junction with the esophagus. This region of the stomach has been the recent focus of intense investigation. Controversy exists as to the nature, location, extent, and even existence of cardiac mucosa. The fundus projects upward, above the cardia and gastroesophageal junction. This dome-shaped area of the stomach is its most superior portion and is in contact above with the left hemidiaphragm and to the left with the spleen. The body, or corpus, the largest portion of the stomach, is located immediately below and continuous with the fundus. The incisura angularis, a fixed, sharp indentation two thirds of the distance down the lesser curvature, marks the caudal aspect of the gastric body (Fig. 45-3). The gastric antrum extends from its indistinct border with the body to the junction of the pylorus with the duodenum. These gross anatomic landmarks correspond roughly with the mucosal histology because antral mucosa (pyloric gland mucosa) actually extends from an area on the lesser curvature somewhat above the incisura. The pylorus (pyloric channel) is a tubular structure joining the duodenum to the stomach and contains the palpable circular muscle, the pyloric sphincter. The pylorus is somewhat mobile owing to its enclosure between the peritoneum of the greater and lesser omenta but is generally located 2 cm to the right of midline at L1. Corresponding motor and secretory functions of these regions of the stomach are discussed in detail in Chapters 46 and 47.
Figure 45-2  Anatomic regions of the stomach. The line is drawn from the incisura angularis along the lesser curvature to an indistinct border between the gastric body and antrum along the greater curvature.  (From Johnson LR: Gastrointestinal Physiology, 6th ed. St Louis, CV Mosby, 2001, p 76.)
Figure 45-3  Film from an upper gastrointestinal series demonstrating the incisura angularis (arrow) on the distal lesser curvature.  (Courtesy James W. Weaver, MD.)

VASCULAR SUPPLY AND DRAINAGE; LYMPHATIC DRAINAGE

The arterial blood supply to the stomach is derived from branches of the celiac artery—common hepatic, left gastric, and splenic arteries—that form two arterial arcades situated along the lesser curvature and the lower two thirds of the greater curvature. The lesser curvature is supplied from above by the left gastric artery and from below by the right gastric artery, a branch of the common hepatic artery or gastroduodenal artery (which is a branch of the common hepatic artery). The
greater curvature below the fundus is supplied from above by the left gastroepiploic artery (a branch of the splenic artery) and from below by the right gastroepiploic artery (a branch of the gastroduodenal artery). The right and left gastroepiploic arteries usually terminate by anastomosing, thus completing the greater curvature arterial arcade; occasionally they end without anastomosis. The arterial supply to the gastric fundus and left upper aspect of the greater curvature is via the short gastric arteries, which arise from the splenic artery.

The venous drainage of the stomach generally accompanies the arterial supply, emptying into the portal vein or one of its tributaries, the splenic or superior mesenteric veins. The left and right gastric veins drain the lesser curvature of the stomach. The left gastric vein is also known as the *coronary vein*. The right and left gastroepiploic veins drain the inferior aspect and a portion of the greater curvature of the stomach. The right gastroepiploic vein and several more distal veins become the gastrocolic veins, eventually terminating in the superior mesenteric vein. There is no gastroduodenal vein. The left gastroepiploic vein becomes the splenic vein and later receives the short gastric veins, thus draining the fundus and upper great curvature of the stomach.

Most of the lymphatic drainage of the stomach eventually reaches the celiac nodes after passing through intermediary lymph nodes. Lymphatic channels anastomose freely in the gastric wall, with lymphatic flow directed through one-way valves into one of four groups of nodes. The inferior gastric region drains into subpyloric and omental nodes, then the hepatic nodes, and finally terminates in the celiac nodes. The splenic or superior aspect of the greater curvature lymph initially drains into pancreaticosplenic nodes and then into celiac nodes. The superior gastric or lesser curvature region lymph drains into the left and right gastric nodes adjacent to their respective vessels and terminates in the celiac nodes. The hepatic or pyloric portion of the lesser curvature lymph drains into the suprapyloric nodes, then into the hepatic nodes, and finally, into the celiac nodes.

**GASTRIC INNERVATION**

The autonomic innervation of the stomach stems from both the sympathetic and parasympathetic nervous systems delivered via a complex tangle of nerves coursing along the visceral arteries.

The gastric sympathetic innervation is derived from preganglionic fibers arising predominantly from T6 to T8 spinal nerves, which synapse within the bilateral celiac ganglia to neurons whose postganglionic fibers course through the celiac plexus along the vascular supply of the stomach. Accompanying these sympathetic nerves are afferent pain-transmitting fibers from the stomach and motor fibers to the pyloric sphincter.

The parasympathetic innervation is via the right and left vagus nerves, which form the distal esophageal plexus, which gives rise to the posterior and anterior vagal trunks near the gastric cardia. The trunks contain preganglionic parasympathetic fibers, as well as afferent fibers from the viscera. Both trunks give rise to celiac and hepatic branches before continuing on within the lesser omentum slightly to the right of the lesser curvature as the anterior nerve of Latarjet and the posterior nerve of Latarjet. These nerves give rise to multiple gastric branches to the stomach wall, where the preganglionic fibers synapse with the ganglion cells in the submucosal (Meissner's) and
myenteric (Auerbach's) plexuses. From these plexuses, postganglionic fibers are distributed to secretory components including cells and glands and to motor components such as muscle.

**TISSUE LAYERS OF THE STOMACH**

The luminal surface of the gastric wall forms thick, longitudinally oriented folds or rugae, which flatten with distention. Four layers make up the gastric wall: mucosa, submucosa, muscularis propria, and serosa. Mucosa lines the gastric lumen, appearing as a smooth, velvety, blood-filled lining. The mucosa of the cardia, antrum, and pylorus is somewhat paler than that of the fundus and body. It is within the gastric mucosa that most of the functional secretory elements of the stomach are located (see Chapter 47). The submucosa, immediately deep to the mucosa, provides the dense connective tissue skeleton of collagen and elastin fibers. Lymphocytes, plasma cells, arterioles, venules, lymphatics, and the submucosal plexus are also contained within the submucosa. The third tissue layer, the muscularis propria, is a combination of three muscle layers: inner oblique, middle circular, and outer longitudinal. The inner oblique muscle fibers course over the gastric fundus, covering the anterior and posterior aspects of the stomach wall. The middle circular fibers encircle the body of the stomach, thickening distally to become the pyloric sphincter. The outer longitudinal muscle fibers course primarily along the greater and lesser curvatures of the stomach. The final layer of the stomach is the transparent serosa, a continuation of the visceral peritoneum.

**MICROSCOPIC ANATOMY**

The gastric mucosal surface is composed primarily of a simple layer of columnar epithelial cells 20 to 40 mm in height. These surface mucous cells (Fig. 45-4), which are similar throughout the stomach, contain basally located nuclei, prominent Golgi stacks, and dense cytoplasm with especially apically dense mucin-containing membrane-bound granules. The cells secrete mucus in granules, which are released via exocytosis, apical expulsion, and cell exfoliation. The primary role of mucus, along with bicarbonate, is luminal cytoprotection from "the elements": acid, pepsin, ingested substances, and pathogens. Cellular renewal time for a gastric surface mucous cell is approximately 3 days.
The surface epithelial lining is invaginated by gastric pits, or foveolae, which provide the gastric glands access to the gastric lumen, with a ratio of one pit to four or five gastric glands. The gastric glands of different anatomic regions of the stomach are lined with different types of specialized epithelial cells, allowing for differentiation of these regions by type of gastric gland (see Fig. 45-2). The first region, the cardia, is a small transition zone from esophageal squamous epithelium to gastric columnar epithelium. The cardia has been a controversial histologic area of discussion with theories suggesting that its presence is pathologic. However, recent observations concluded that cardiac mucosa develops during gestation and is present at birth. The cardiac glands have a branched and tortuous configuration and are populated by mucous, endocrine, and
undifferentiated cells. There is a gradual transition from cardiac glands to the second region, the acid-secreting segment of the stomach. This region encompasses the gastric fundus and body and contains the parietal (or oxyntic or fundic) glands. Parietal, chief (also known as peptic), endocrine, mucous neck, and undifferentiated cells compose the oxyntic glands. The final region, corresponding to the antrum and pylorus, contains the pyloric glands, composed of endocrine cells, including gastrin-producing G cells and mucous cells.

By far the most numerous and distinctive gastric glands are the oxyntic glands (Fig. 45-5), responsible for the secretion of acid, intrinsic factor, and most gastric enzymes. These fairly straight and simple tubular glands are closely associated in the areas of gastric fundus and body. A typical gland is subdivided into three areas: the isthmus (where surface mucous cells predominate), the neck (where parietal and mucous neck cells predominate), and the base (where chief cells predominate, along with some parietal and mucous neck cells). Endocrine cells, somatostatin-containing D cells, and histamine-secreting enterochromaffin-like (ECL) cells are scattered throughout the oxyntic epithelium.
The principal cell type of the oxyntic gland is the parietal cell (Fig. 45-6), responsible for the oxyntic mucosal secretion of $3 \times 10^6$ hydrogen ions per second, at a final HCl concentration of around 150 mmol/L. Parietal cells bulge into the lumina of the oxyntic glands and, as the primary hydrogen secretors, have ultrastructural characteristics different from other gastric cells: large mitochondria, microvilli lacking in glycocalyx, and a cytoplasmic canaliculi system in contact with the lumen. In the nonsecreting parietal cell, a cytoplasmic tubulovesicular system predominates and short microvilli line the apical canaliculus. In the secreting state, the tubulovesicular system disappears, leaving an extensive system of intracellular canaliculi containing long microvilli. Mitochondria occupy approximately 30% to 40% of the secreting parietal cell volume, providing energy required for acid secretion across apical microvilli (see Fig. 45-6). The so-called proton pump—the H/K-ATPase—resides in the apical microvillus membrane, as does carbonic anhydrase. The apical H/K-ATPase functions as the proton translocator in gastric acid secretion (see Chapter 47). Acid secretion begins within 5 to 10 minutes of stimulation. Additionally, parietal cells are the site of intrinsic factor secretion via membrane-associated vesicle transport.

Figure 45-5  Schematic representation of an oxyntic (gastric) gland, with mucous surface cells (MSC), mucous neck cells (MNC), enterochromaffin-like (ECL) cells, somatostatin containing D cells (D cell), parietal cells (PC), and chief cells (CC). (From Lloyd KCK, Debas T: The peripheral regulation of gastric acid secretion. In Johnson LR, et al [eds]: Physiology of the Gastrointestinal Tract, vol 2, 3rd ed. New York, Lippincott-Raven, 1994.)

Figure 45-6  Parietal cell. A, Electron photomicrograph. B, Schematic. (A and B, From
Closely associated with parietal cells are mucous neck cells, which appear singly, close to parietal cells or in groups of two or three in the oxyntic gland neck or isthmus. Mucous neck cells differ from their surface counterparts in their synthesis of acidic, sulfated mucus rather than the neutral mucus. Additionally, mucous neck cells have basal nuclei and larger mucous granules around the nucleus rather than apically located granules. Function of the two cell types appears different in that surface mucous cells are cytoprotective, whereas the mucous neck cell functions as a stem cell precursor for surface mucous, parietal, chief, and endocrine cells.

Chief cells, also known as zymogen cells, predominate in deeper layers of the oxyntic glands. These pyramid-shaped cells play a role in synthesis and secretion of pepsinogens I and II. The cytoplasm of chief cells has prominent basophilic staining owing to abundance of ribosomes; these ribosomes are either free in cytoplasm or in association with an extensive endoplasmic reticulum system. Zymogen granules lie in the apical cytoplasm; their contents are released into the gastric lumen following fusion of the limiting membrane of the granule with the luminal membrane. Once in the lumen, pepsinogens are converted to pepsin.

A variety of endocrine, or enteroendocrine, cells are scattered among the cells of the oxyntic glands. These cells vary in location, being either open or closed relative to the gastric lumen. Open endocrine cells have apical membranes containing receptors; these open cells discharge their contents by basilar exocytosis into the bloodstream, thus exerting an endocrine effect. The closed endocrine cells contain several processes that terminate near its target cells, constituting the so-called paracrine effect. The oxyntic gland model of the closed cell is the D cell, which secretes somatostatin via long processes reaching ECL, parietal, and chief cells.

Enterendocrine cell types have also been classified by their granular staining with silver or chromium. Those cells containing granules that reduce silver without pretreatment are called argentaffin cells. Argentaffin cells that stain with potassium dichromate are termed enterochromaffin (EC) cells; most of these contain serotonin. Cells with granules staining with silver only in the presence of a reducing agent are called argyrophilic, or ECL cells. Located primarily in the oxyntic glands, ECL cells are the only enteroendocrine cells containing histamine.

The final region of the stomach encompasses the antrum and pylorus and contains extensively coiled antral glands composed of endocrine and epithelial cells. The epithelial cells are predominantly mucous cells, and there are small numbers of pepsinogen II-secreting oxyntic cells. Although also small in number, gastrin-secreting (G) cells play a vital physiologic role and are the prototype of the open enteroendocrine cell. These cells, which occur either singly or in small clusters in the mid to deep sections of antral glands (Fig. 45-7A), contain a basilar cytoplasm densely packed with gastrin-containing secretory granules (Fig. 45-7B). Gastrin release is stimulated by gastric distention, vagal stimulation, dietary amino acids, and peptide, with rapid
appearance of the hormone into the bloodstream in the postprandial period (see Chapter 47). The apical or luminal surface of the G cell is narrowed into small microvilli thought to contain receptors responsible for amino acid and peptide stimulation of gastrin release. Significant quantities of gastrin are also secreted into the gastric lumen; gastrin is a known gastric growth and differentiation factor, mediated through upregulation of heparin-binding epidermal-like growth factor (HB-EGF) in gastric parietal cells.\textsuperscript{4,5}

![Figure 45-7](image)

**Figure 45-7** Gastrin (G) cells. A, Scattered G cells (pink) are evident in pyloric glands on this photomicrograph (immunoperoxidase stain). B, Schematic representation of a G cell.

Antral enteroendocrine D cells found in close association with G cells manufacture somatostatin, a potent inhibitor of gastrin secretion. The D cells are also present in small numbers in oxyntic glands. Somatostatin is thought to inhibit acid secretion through paracrine (direct action on ECL and perhaps parietal cells or indirect action on G cells) or endocrine effects (direct action on parietal cells) (see Chapter 47 for more details).

Immediately deep to the basement membrane of the gastric mucosa epithelial layer lies the lamina propria, which contains a variety of leukocytes (polymorphonuclear leukocytes, plasma cells, lymphocytes, eosinophils), mast cells, fibroblasts, and endocrine-like cells. A few lymphatic channels course through the lamina propria. Additionally, the mucosal capillary plexus lies in the lamina propria and forms a venule plexus, which communicates with the venules in the muscularis mucosa. These venules eventually empty into veins of the submucosa.

**ANATOMY OF THE DUODENUM**

**GENERAL CONSIDERATIONS**
The duodenum is the most proximal section of the small intestine and is continuous proximally with the pylorus and distally with the jejunum. It forms a C-shaped loop around the head of the pancreas. In the adult the length of the duodenum is approximately 30 cm (12 inches, hence its name *duodenum*) and is subdivided into four sections (commonly termed the *first, second, third,* and *fourth* parts), whose borders are delineated by angular course changes.

The first part of the duodenum is about 5 cm in length and courses rightward, upward, and backward from the pylorus. The proximal portion of the first part of the duodenum is also referred to as the *duodenal bulb or cap.* Loosely attached to the liver by the hepatoduodenal portion of the lesser omentum, the first part moves in response to movement by the pylorus. The gastroduodenal artery, the common bile duct, and the portal vein lie posterior, whereas the gallbladder lies anterior to the first part of the duodenum. The second part of the duodenum is 7 to 10 cm in length, coursing downward parallel and in front of the hilum of the right kidney and to the right in contact with the pancreatic head. Slightly inferior to the midpoint of the second part of the duodenum on the posteromedial wall, the nipple-like major duodenal papilla marks the location of the *ampulla of Vater,* through which the pancreaticobiliary ducts empty into the duodenum. On the same wall 2 cm proximal to the major papilla, there may be a minor duodenal papilla that forms the opening for the accessory pancreatic duct. The third part of the duodenum is about 10 cm in length and courses transversely from right to left, crossing the midline anterior to the spine, aorta, and inferior vena cava. The superior mesenteric artery and vein course anterior to the third part of the duodenum generally to the right of midline. The fourth and final section of the duodenum is 5 cm long and courses upward to the left of the aorta to reach the inferior border of the pancreas. The junction between the duodenum and the *jejunum (duodenojejunal flexure)* is fixed posteriorly by the *ligament of Treitz.*

The duodenal wall is composed of outer longitudinal and inner circular muscle layers. As is the case with the remainder of the small intestine, the luminal surface is lined with mucosa, forming circular folds known as the *plicae circulares* or *valvulae conniventes.* An exception to this is the duodenal bulb, distinguished radiographically and endoscopically by its smooth, featureless mucosa.

The first few centimeters of the duodenum are shrouded by anterior and posterior elements of the peritoneum. The remainder of the duodenum lies posterior to the peritoneum and thus is retroperitoneal.

The duodenum develops during the fourth week of gestation from the distal foregut, proximal midgut, and the adjacent splanchnic mesenchyme. The junction of the foregut and midgut occurs in the second part of the duodenum, slightly distal to the major papilla. As the stomach rotates, so too does the duodenum, thus developing a C-shaped configuration. During weeks 5 and 6 of embryologic development, the duodenal lumen is temporarily obliterated owing to proliferation of its mucosal lining. During the following weeks, luminal vacuolization and degeneration of some of the proliferating cells result in recanalization of the duodenal lumen. Epithelium and glands develop from embryonic endoderm, whereas connective tissue, muscle, and serosa are derived from mesoderm.

**VASCULAR SUPPLY AND DRAINAGE; LYMPHATIC DRAINAGE**
The arterial supply to the duodenum is based on its embryonic origin in that branches of the celiac trunk (as derived from foregut) supply the proximal duodenum, whereas the distal duodenum (as derived from midgut) is supplied by branches of the superior mesenteric artery. From the celiac trunk arises the common hepatic artery, from which arises the gastroduodenal artery. The gastroduodenal artery in turn branches into the superior pancreaticoduodenal artery, which gives off anterior and posterior branches to the duodenum. These branches anastomose with analogous branches of the inferior pancreaticoduodenal artery, a branch of the superior mesenteric artery.

The venous drainage corresponds to the arterial supply, with the superior pancreaticoduodenal veins coursing between the duodenum and pancreatic head to enter the portal vein. Likewise, both anterior and posterior inferior pancreaticoduodenal veins empty into either a jejunal vein or directly into the superior mesenteric vein.

The duodenal lymphatic drainage also corresponds to the vascular supply. Small anterior and posterior duodenal lymph channels drain into the pancreaticoduodenal nodes. From these nodes, lymph drains superiorly into the hepatic nodes or inferiorly into superior mesenteric nodes located at the origin of the superior mesenteric artery.

**DUODENAL INNERVATION**

As in the case in the stomach, duodenal innervation is provided by both sympathetic and parasympathetic nervous systems. The preganglionic sympathetic nerves course through the celiac and superior mesenteric ganglia, with postganglionic neurons entering the duodenal intramural plexuses. Afferent fibers accompany the sympathetic neurons, primarily carrying fibers for visceral pain sensation. Parasympathetic fibers, supplied by the hepatic branch of the anterior vagus nerve and the mesenteric nerves, synapse with Meissner's and Auerbach's plexuses in the duodenal wall.

**MICROSCOPIC ANATOMY**

Microscopically, the duodenum differs dramatically from the gastric mucosa with the change from gastric glands and pits to a mucosa lined with villi surrounded by crypts of Lieberkühn and submucosa with characteristic Brunner's glands. A single layer of epithelial cells provides the interface between the duodenal lumen and mucosa in the areas of both villi and crypts. Deep to this epithelial layer are contained absorptive cells, Paneth cells (which secrete lysozyme and other host defense factors), mucous cells, and endocrine cells.

The villi in the proximal duodenum have a distorted appearance thought to be related to gastric acid. In contrast, the villi of the distal duodenum are tall, slender, and very regular, similar to those in the jejunum. The ratio of villi to crypts in the distal duodenum is 4:1 or 5:1, again similar to the ratio in the jejunum. Within the submucosa of the duodenum are located the branched Brunner's glands, which secrete an alkaline and clear mucus containing bicarbonate, epidermal growth factor, and pepsinogen II. Brunner's glands are most numerous in the proximal duodenum and decrease in number distally. Rather than emptying into the duodenum through their own duct system, Brunner's glands empty into the duodenum through adjacent intestinal glands.