K. DIGESTIVE SYSTEM
OVERVIEW OF THE SYSTEM

When coloring the organs that overlap each other, use your lightest colors for D, E, T, V, and W. Each overlapping portion receives the color of both structures. (1) After coloring the alimentary canal, review the structures before completing the accessory organs. The central section of the transverse colon (J) has been removed to show deeper structures.

ALIMENTARY CANAL:
- ORAL CAVITY A
- PHARYNX B
- ESOPHAGUS C
- STOMACH D
- SMALL INTESTINE:
  - DUODENUM E
  - JEJUNUM F
  - ILEUM G
- LARGE INTESTINE:
  - CECUM H
  - VERMIFORM APPENDIX H
  - ASCENDING COLON I
  - TRANSVERSE COLON J
  - DESCENDING COLON K
  - SIGMOID COLON L
  - RECTUM M
  - ANAL CANAL N

ACCESSORY ORGANS:
- TEETH O
- TONGUE P
- SALIVARY GLANDS:
  - SUBLINGUAL Q
  - SUBMANDIBULAR R
  - PAROTID S
- LIVER T
- GALL BLADDER U
- BILE DUCTS V
- PANCREAS W

The digestive system consists of an alimentary canal with accessory organs. The canal begins with the oral cavity. Here the teeth pulverize ingested food while it is softened and partly digested by salivary gland secretions. The tongue aids in mechanical manipulation of the food, and literally flips the food into the fibromuscular pharynx during swallowing.

The esophagus moves the bolus along to the stomach by peristaltic muscular contractions. Here the bolus is treated to mechanical and chemical digestion, then passed into the highly coiled small intestine for more enzymatic and mechanical digestive processes. Small molecular nutrients are extracted, absorbed by lining cells, and transferred to capillaries. Liver-produced bile, stored in the gall bladder, is discharged into the duodenum by bile ducts. Digestive enzymes from the pancreas enter the duodenum as well. The large intestine is mainly concerned with absorption of water, minerals, and certain vitamins. The non-nutritive residue of the ingested bolus is moved through the rectum and anal canal to the outside. Nutrients absorbed throughout the tract are transported to the liver by the hepatic portal system for processing and distribution to the body's cells.
K. DIGESTIVE SYSTEM

ORAL CAVITY & TONGUE

ON: Use pink for K and very light colors for A, B, T, U, and V. Do not color the teeth. (1) When coloring the mouth, also color many of those structures that appear in the sagittal view. (2) It is not necessary to color all of the papillae of C and R.

FRENULUM OF LIP
GINGIVA (GUM)
HARD PALATE
SOFT PALATE
UVULA
PALATOGLOSSAL ARCH
OROPHARYNX
PALATOPHARYNX
GEAL ARCH
TONSILLAR FOSSA
PALATINE TONSIL
TONGUE
BUCCINATOR MUSCLE
BUCCAL FAT

The human mouth is concerned with vocalization as well as mastication and swallowing (deglutition). Its anterior half, including teeth, muscular tongue and related extrinsic muscles, salivary glands, hard (bony) palate, and buccinator muscle in the cheek wall, is concerned with wetting, macerating, and pulverizing ingested material. Thousands of mucous glands in the stratified squamous-lined mucosa of the mouth assist in these functions, as do the multiple, microscopically-towering papillae on the surface of the tongue, the latter forming an abrasive surface for mechanical digestion. The temporomandibular joints permit a fairly wide range of lower jaw motion and mouth opening (35-50 mm inter- nal range in the adult). The posterior half of the mouth, including soft (muscular) palate, tongue, and tonsils between the muscular arches, is concerned with immune defense and propelling the mechanically treated food into the pharynx. Sense receptors (taste buds) buried among the papillae on the tongue surface are responsive to chemical stimuli dissolved in the saliva. These receptors are arranged in a pattern reflecting specific sensitivity to molecular variations, i.e., bitter, sour, salt, and sweet tastes.

SALIVARY GLANDS:
SUBLINGUAL
SUBMANDIBULAR
PAROTID

Salivary glands secrete a mixed water/mucus, enzyme-containing fluid into the mouth during periods of eating (or anticipated eating). Specialized muscle (myoepithelial) cells at the base of the glands stimulate secretion into the ducts following stimulation by autonomic nerves. The sublingual glands are the smallest of the three paired glands. Their ducts open on to the floor of the mouth, as do the ducts of the submandibular gland. The parotid gland is the largest, sending its duct across the masseter muscle, through the cheek, and into the oral cavity opposite the upper 2nd molar tooth.
X. DIGESTIVE SYSTEM

ANATOMY OF A TOOTH

I Use yellow for F, red for G, blue for H, and light colors for A, B, and L.
II Begin with the anatomy of a tooth. Color gray the titles and arrows/bands arranged vertically. (2) Use only light colors on the teeth below. You may repeat colors used on the upper illustration. Note that the identifying letter and numerical labels are those used by the dental profession.

ENAMEL

DENTIN

PULP CAVITY

ROOT CANAL

PULP

NERVE. ARTERY. VEIN

CEMENTUM

PERIODONTAL MEMBRANE

GINGIVA

ALVEOLAR BONE

The tooth is a hollow core of sensitive, mineralized dentin filled with a loose fibrous, vascular pulp, capped with insensitive mineralized enamel projecting above the gingiva (gum) or buried within the bony socket (alveolus) and secured to that periodontal-lined bone by cementum. The bulk of the tooth is rooted in bone; the neck of the tooth is at the gum line. The crown is dentin covered with 1-1.5 mm thick enamel. Enamel is the hardest substance in the body, weighing in at 99% mineral content. It consists of circular rods arranged in a wave pattern surrounded by hydroxyapatite (bone) mineral crystals. During development, non-mineralized enamel (it mineralizes later) is secreted by cells which are worn off the enamel surface when the tooth erupts and becomes exposed.

Dentin is a bone-like material (70% mineral by weight) secreted in tabular form by cells at the dentin-pulp junction. With aging, the pulp diminishes in volume, replaced by dentin. The pulp cavity is filled with an embryonic connective tissue supporting nerves, arteries, and veins that supply the tooth. Pulp passes through a root (or pulp) canal to reach the apical or root foramen. The pulp is continuous with the periodontal membrane, a dense fibrous tissue similar to periosteum. Cementum is like bone, mineralized with a significant content of collagen fibers. It serves as an intermediate tissue between dentin and the periodontal membrane, with many of its fibers buried in alveolar bone. The gingiva, lined with keratinized stratified squamous epithelium, is part of the mucous membrane of the mouth, and surrounds the neck of each tooth. The gingival epithelial cells are attached to the tooth surface. The gingiva is firmly anchored to the periosteum of the underlying alveolar bone.

ADULT/CHILD DENTITION:

CENTRAL INCISOR 6, 8, 9, 24, 25, E, F, P
LATERAL INCISOR 7, 10, 23, 26, D, G, N, Q
CANINE 6, 11, 22, 27, C, H, M, R
1ST PREMOLAR 5, 12, 21, 28
2ND PREMOLAR 4, 13, 20, 29
1ST MOLAR 9, 14, 19, 30, B, I, L, S
2ND MOLAR 2, 15, 18, 31, A, J, K, T
3RD MOLAR (WISEDTH) 1, 16, 17, 32

Two sets of teeth develop within a lifetime. The first set are deciduous (milk teeth). There are 20 in each jaw. The incisors are usually the first to erupt at about 6 months; the rest follow within 36 months after birth. Pressure from the permanent teeth induce osteoclastic resorption of the milk teeth roots, and subsequently the remaining crowns dislodge and fall out without pain or bleeding. In the permanent set, the first molar or central incisor erupts first (at about 6 years). The second molar erupts around 11 years of age; the third molar generally emerges about 18 years ("wisdom tooth").
**X. DIGESTIVE SYSTEM**

**PHARYNX & ESOPHAGUS**

Ch: Use pink for K. (1) Color the three lower illustrations simultaneously. In the posterior view of the interior of the pharynx, the posterior pharyngeal wall is divided and retracted so you can note the relationship of internal pharyngeal structures to the constrictor muscles (A, B, C) and the subdivisions of the pharynx (D, E, F). Color gray the boluses of food in both upper and middle lower views, and the ides at upper right. (2) Follow the text when coloring the deglutition diagrams.

**MUSCULAR WALL OF PHARYNX:**

- **SUPERIOR CONSTRICCTOR**
- **MIDDLE CONSTRICCTOR**
- **INFERIOR CONSTRICCTOR**

**INTERIOR OF PHARYNX:**

- **NASOPHARYNX**
- **SOFT PALATE**
- **UVULA**
- **OROPHARYNX**
- **PALATINE TONSIL**
- **LARYNGOPHARYNX**
- **ESOPHAGUS**

**RELATED STRUCTURES:**

- **TONGUE**
- **HYOID BONE**
- **THYROID CARTILAGE**
- **CRICOID CARTILAGE**
- **MUSCLES**
- **NASAL CAVITY**
- **EPIGLOTTIS**
- **LARYNX**

The pharynx is a complex fibromuscular, mucosa-lined sac, open to the nasopharynx above, the oral cavity in front, and the larynx and esophagus below. Like three stacked pots, the constrictor muscles of the pharyngeal wall overlap one another posteriorly and posterolaterally. Several small muscles (not shown) reinforce the constrictor muscles structurally and functionally. The pharyngeal muscles are primarily concerned with deglutition. Swallowing begins with pushing the food bolus from the oral cavity into the oropharynx (1). This is done with the tongue assisted by the suprahypoid muscles pulling the hyoid bone and larynx upward. The soft palate (levator palati) then elevates and the superior constrictors contract, closing off the nasopharynx. Incarcerated in the oral pharynx, unable to return to the mouth or enter the nasal cavity, the bolus shoots into the laryngopharynx (2) with the aid of the middle and inferior constrictors, past the closed larynx (pinched off by the aryepiglottid folds) and into the esophagus.
With the anterior abdominal wall opened through its deepest (parietal peritoneal) layer, the liver, stomach, and the fatty greater omentum are generally all that can be seen with the contents undisturbed. Lifting the liver exposes the lesser omentum, a double-peritoneal layer between stomach and liver. It is the anterior wall of the omental bursa (E). The greater omentum connects the transverse colon to the stomach.

With the greater omentum lifted, the double-layered, transverse mesocolon between transverse colon and the parietal peritoneum can be seen. Retracting the intestines to one side reveals the common mesentery between most of the small intestine and the parietal peritoneum on the posterior body wall. The sigmoid colon has a mesentery (sigmoid mesocolon) as well. Abdominal structures posterior to these mesenteries/omenta are retroperitoneal.

The parietal peritoneum of the posterior body wall is seen when all structures except retroperitoneal ones (aorta, inferior vena cava, kidneys, ureters, pancreas, duodenum, ascending/descending colon) are removed. Many nerves and vessels travel in this retroperitoneal space. As organs emerge from the peritoneum, they develop a mesentery to suspend them. The cut layers of several of them can be seen (C, D, F, G, and H).

PERITONEAL STRUCTURES:

PARietAL PERITONEUM

PERITONEAL CAVITY

LESSER OMENTUM

OMENTAL BURSA

GREATER OMENTUM

TRANSVERSE MECSCOLON

COMMON MESENTERY

SIGMOID MECSCOLON

VICERAL PERITONEUM

Peritoneum is a serosal membrane of the abdominal cavity. The disposition of the peritoneum is similar to that of the serosal layers around heart (pericardium) and lungs (pleura); peritoneum attached to the body wall is parietal, peritoneum attached to the outer visceral wall is visceral. Structures deep to the posterior parietal peritoneum are retroperitoneal. Peritoneal layers suspending organs are called mesenteries; those suspending an organ from another organ are called omenta or ligaments. When coloring the sagittal view, the continuity of these peritoneal membranes can be appreciated. The cavity of the peritoneum is empty; it can fill with fluid in disease and trauma. The view at right shows intestines separated apart from one another; in life, they are as close together as strands of coiled wet rope. Vessels to the intestines and stomach travel in the mesenteries/omenta; they do not penetrate peritoneal layers. The source vessels are retroperitoneal. The omental bursa is a peritoneal-lined sac created by rotation of the stomach during fetal life. It is open on the right at the epiploic foramen between the lesser omentum and the parietal peritoneum. Here the omental bursa (lesser sac) communicates with the collapsed, empty peritoneal cavity (greater sac).
**K. DIGESTIVE SYSTEM**

**STOMACH**

1. Use light colors for E, L, and O. (1) Color the regions of the stomach. (2) Color simultaneously the large view of the stomach and the section of the stomach wall. The layers of the wall in the large view have been enlarged to facilitate coloring. Note the oblique muscle (3) Color the lower diagram.

**REGIONS:**
- **CARDIA**
- **FUNDUS**
- **BODY**
- **PYLORUS**

**STOMACH WALL:**
- **MUCOSAL SURFACE (RUGAE)**
- **SUBMUCOSA**
- **MUSCULARIS EXTERNA:**
  - **OBLIQUE M.**
  - **CIRCULAR M.**
  - **LONGITUDINAL M.**
- **SEROSA**

The stomach is the first part of the gastrointestinal tract. It acidifies ingested food to enhance protein digestion and kill microorganisms, secretes proteolytic enzymes (pepsin), mechanically manipulates digesting food, and induces secretion of bile and pancreatic enzymes. The cardia is the area of the gastro-esophageal junction; there is no circular muscle here, it relaxes during swallowing. The pylorus is thickened with circular muscle near the duodenal junction (pyloric sphincter). Its regulatory function has been questioned.

While coloring note carefully the organization of the stomach wall; the mucosa is considered below. The fibrous, vascular submucosa provides some support for the larger vessels and nerves traveling in this layer. When the stomach is not full, the mucosa and submucosa are often thrown into a series of irregular folds (rugae). The different orientations of the muscularis externa layer provide complex and effective peristaltic movements during digestion.

The mucosa of the stomach, lined with simple columnar epithelial cells with microvilli, contains a subepithelial vascular, loose, fibrous tissue layer (lamina propria) supporting the gastric glands. It contains numerous fibroblasts and particularly dense masses of lymphocytes (lymphoid follicles, see Plate 84). The fundus and body reveal tubular-shaped gastric glands that exhibit deep gastric pits (a neck (largely mucous cells) and a base containing mucous cells, parietal cells secreting hydrochloric acid, chief cells secreting the protein-lysing enzyme pepsin, and enterodendrine cells secreting gastrointestinal regulatory hormones. The parietal cells also secrete intrinsic factor, a glycoprotein which binds with vitamin B₁₂ and permits the latter's absorption in the ileum of the small intestine. Malabsorption of intrinsic factor leads to vitamin B₁₂ deficiency which induces abnormal erythrocyte (RBC) development and subsequent pernicious anemia. The pylorus contains largely mucous glands as well as enterodendrine cells secreting gastrin, a polypeptide. It stimulates secretion of pepsin and acid in the stomach, and augments gastric muscle contractions (increased motility). The smooth muscle fibers of the thin muscularis mucosae participate in the mechanical digestive process.
X. DIGESTIVE SYSTEM

SMALL INTESTINE

DUODENUM:
- SUPERIOR (1ST) PART:
- DESCENDING (2ND) PART:
- HORIZONTAL (3RD) PART:
- ASCENDING (4TH) PART:
JEJUNUM
ILEUM

INTESTINAL WALL:
- MUCOSA:
- PLICA CIRCULARE (FOLD)
- VILLI
- LAMINA PROPRIA:
- MUSCULARIS MUCOSAE:
- LYMPHOID FOLLICLE:
- SUBMUCOSA:
- MUSCULARIS EXTERNA:
- CIRCULAR M.
- LONGITUDINAL M.
- SEROSA D.

Q: Use green for K, red for R, purple for S, blue for T, yellow for U, and a very light color for H. (1) Begin with the three divisions of the small intestine. (2) Color the parts of the duodenum and the section of duodenal wall. The lamina propria (I) is identified and colored only in the enlarged view of the villi below.

The small intestine is a highly convoluted, thin-walled tube that undertakes much of the chemical and mechanical digestive process and almost the whole of the absorptive process of the entire gastrointestinal tract. The first part of the duodenum is suspended by the lesser omentum. The second and third parts are retroperitoneal. The fourth part emerges anteriorly to become embraced by the common mesentery, pulled upward/suspended by a band of smooth muscle at the duodenojejunal junction. The jejunum is highly coiled, suspended by the common mesentery between the peritoneal layers through which travel its blood and nerve supply and draining veins. The thinner but longer ileum is also suspended by the common mesentery. It opens into the cecum of the large intestine.

The mucosal surface of the jejunum (and to a lesser extent the duodenum and ileum) is characterized by circular folds (plicae circulares). Myriads of conical, finger-shaped villi (leaf-shaped in the duodenum) project from the surface of the jejunum; these diminish in number in the ileum. Among the epithelia lining the villi are hormone-secreting enteroendocrine cells (see glossary). The loose, vascular, fibrous lamina propria support the villi and its contents, including lymphatic capillaries (lacotyes) and muscle fibers from the muscularis mucosae. Lymphoid follicles exist in both lamina propria and submucosa; they increase in number in the ileum where they form aggregates (Peyer's patches). At the base of the villi are tubular intestinal glands, the ducts of which open into the intervillus spaces. The submucosa of the small intestine is fibrous and vascular; and contains ganglia of autonomic motor neurons, the axes of which supply the muscularis externa. In the duodenum only, mucus-secreting glands occupy the submucosa.

ABSORPTIVE CELL
MUCOUS CELL
ENTEROENDOCRINE CELL
GLANDULAR DUCT
ARTERY
CAPILLARY
VEIN
NERVE
LACTEAL
LARGE INTESTINE:

ILEOCECAL VALVE:
VERMIFORM APPENDIX:
ASCENDING COLON:
TRANSVERSE COLON:
DESCENDING COLON:
SIGMOID (PELVIC) COLON:
RECTUM:
ANAL CANAL:
INTERNAL SPHINCTER ANI:
EXTERNAL SPHINCTER ANI:
TAENIA COLI:
APPENDICES EPICLICA:

INTESTINAL WALL:
MUCOSA:
EPITHELIUM / MUCUS:
GLANDS:
LAMINA PROPRIA:
MUSCULARIS MUCOSAE:
SUBMUCOSA:
MUSCULARIS EXTERNA:
CIRCULAR M.:
LONGITUDINAL M.:
SEROSA:

The large intestine is characterized by large sacculations (heastrae), strips of longitudinal muscle in the muscularis externa (taenia coli), and fat pads (appendices epiploica) attached to the serosal surface of the ascending, transverse, and descending colon (only). The large intestine begins at the ileocecal valve with the cecum, usually suspended by a mesentery, in the right lower abdominal quadrant. The function of the valve is not clear. The vermiform appendix varies in length (2-20 cm), it may lie anterior, posterior, or inferior to the cecum. The ascending and descending colon are retroperitoneal; the transverse colon is suspended by a mesentery (transverse mesocolon). Note the colic flexures and their relationships. At the pelvic inlet (not shown), the colon turns medially, gains a mesentery (sigmoid mesocolon), and is named the sigmoid colon. Variable in its extent and shape, it becomes the rectum at the level of the S3 vertebra. Here the hastrae, the appendices epiploica, and the taeniae are no longer seen. About 12 cm long, the rectum has a dilated lower part (ampulla). Feces entering the rectum stimulate the desire for defecation; thus, the rectum is not a long-term storage site. As the rectum narrows inferiorly, it becomes the anal canal surrounded by sphincter muscles.

The intestinal wall of the large intestine is characteristic: mucosal surface without villi or plicae, underlying vascular submucosa, and two-layered muscularis externa lined with peritoneal serosa. The epithelial lining is simple columnar except in the anal canal where it becomes stratified squamous. The glands are tubular and mucus-secreting. lymphoid follicles are seen in the lamina propria. At the anorectal junction, about 2 cm above the anus, a remarkably large number of veins can be seen in the lamina propria (not shown). Varicose dilatations of these veins (rectal or hemorrhoidal plexus) are called hemorrhoids. The large intestine functions in absorption of water, vitamins, and minerals, and the secretion of mucus.
The liver is the largest gland in the body. Wedge-shaped (rounded upper border, sharp inferior border) when seen from the side, the liver occupies the whole of the upper right quadrant of the abdominal cavity. Weighing about 1.5 kg in men, it can weigh over 10 kg when diseased (chronic cirrhosis). It is relatively small in young children, hence the protuberance of the upper abdomen in such persons. The liver is enveloped in visceral peritoneum except for a part of the posterior surface which is flush against the fascia covering the diaphragm (bare area). The visceral peritoneum around the bare area turns or reflects upward (coronary ligaments) on to the diaphragm to become parietal peritoneum.

The edges of the coronary ligaments are called the triangular ligaments. The two anterior leaves of the coronary ligaments join to become the falciform ligament; the two posterior leaves become the lesser omentum which encircles the porta of the liver. Here the hepatic portal vein and the hepatic artery approach the visceral surface of the liver and branch, and the common bile duct receives the common hepatic duct and cystic duct. The two-layered lesser omentum depends to support the pyloric end of the stomach and the first part of the duodenum. The falciform ligament is continuous with the parietal peritoneum of the anterior abdominal wall.

Connective tissue septa divide the liver cells/tissue (parenchyma) into irregular polyhedral lobules. Within each lobule, the cells form radially arranged cords; on two surfaces of these cords are sinusoids that converge onto a core or less central vein. At the corners of these lobules are the hepatic artery and portal vein branches, and bile ducts (called a triad). The portal vein branches feed into the sinusoids; the hepatic artery branches supply the cells; the bile ducts drain the bile ductules formed from tiny canaliculi (not shown) surrounding the cells. The liver cells discharge their products into the sinusoids (except bile), and absorb from these same sinusoids various solutes and non-nutrients as well. Liver cells store and release proteins, phospholipids, lipids, iron, and certain vitamins (A, D, E, K); they manufacture urea from amino acids, and bile from pigments and salts; they detoxify many harmful ingested substances. Bile is released from the cells into tributaries of bile ducts. The central veins are tributaries of larger veins which merge to form three hepatic veins at the posterior, superior aspect of the liver. These veins join the inferior vena cava just inferior to the diaphragm.
The biliary system consists of an arrangement of ducts transporting bile from the liver cells that manufacture it to the gall bladder and to the second part of the duodenum. It is worth repeating; bile is formed in the liver (not the gall bladder). It is a fluid consisting largely of water (97%), and bile salts and pigments (from the breakdown products of hemoglobin in the spleen). Once formed, bile is discharged from liver cells into surrounding bile canaliculi. These small canals merge to form bile ductules that join the bile ducts which travel in company with the branches of the portal vein and hepatic artery. The bile is brought out of the liver by the right and left hepatic ducts which merge at the porta to form the common hepatic duct which descends between the layers of the lesser omentum and receives the 4 cm-long cystic duct from the gall bladder. The gall bladder is pressed against the visceral surface of the right lobe of the liver, covered with visceral peritoneum. The common bile duct (or just bile duct) is formed by the cystic and common hepatic duct. About 8 cm long, it descends behind the first part of the duodenum, deep to or through the head of the pancreas. It usually joins with the main pancreatic duct, forming an ampulla in the wall of the second part of the duodenum. Here the duct opens into the lumen of the duodenum. There can be variations in the union of these two ducts.

The gall bladder serves as a storage chamber for bile discharged from the liver. Bile is concentrated here several times, a fact reflected in the multiple microvilli on the luminal surfaces of the simple columnar epithelial cells that absorb water from the dilute bile. In response to the gastric or duodenal presence of fat, secretion of cholecystokinin is induced which stimulates the gall bladder to discharge its contents into the cystic duct. Peristaltic contractions of the duct musculature squirts bile into the duodenal lumen through the ampullary sphincter. Bile saponifies and emulsifies fats, making them water soluble and amenable to digestion by enzymes (lipases). The pancreas is a gland in the retroperitoneum, consisting of a head, neck, body, and tail. Most of the pancreas consists of exocrine glands that secrete enzymes into the pancreatic duct tributaries and on into the duodenum at a rate of about 2000 ml per 24 hour day. These enzymes are responsible for a major part of chemical digestion in the small intestine (lipases for fat, peptidases for protein, amylases for carbohydrates, and others). Pancreatic secretion is regulated by hormones (primarily cholecystokinin and secretin) from entero-endocrine cells and by the vagus nerves (acetylcholine). The endocrine portion of the pancreas is covered in Plate 129.