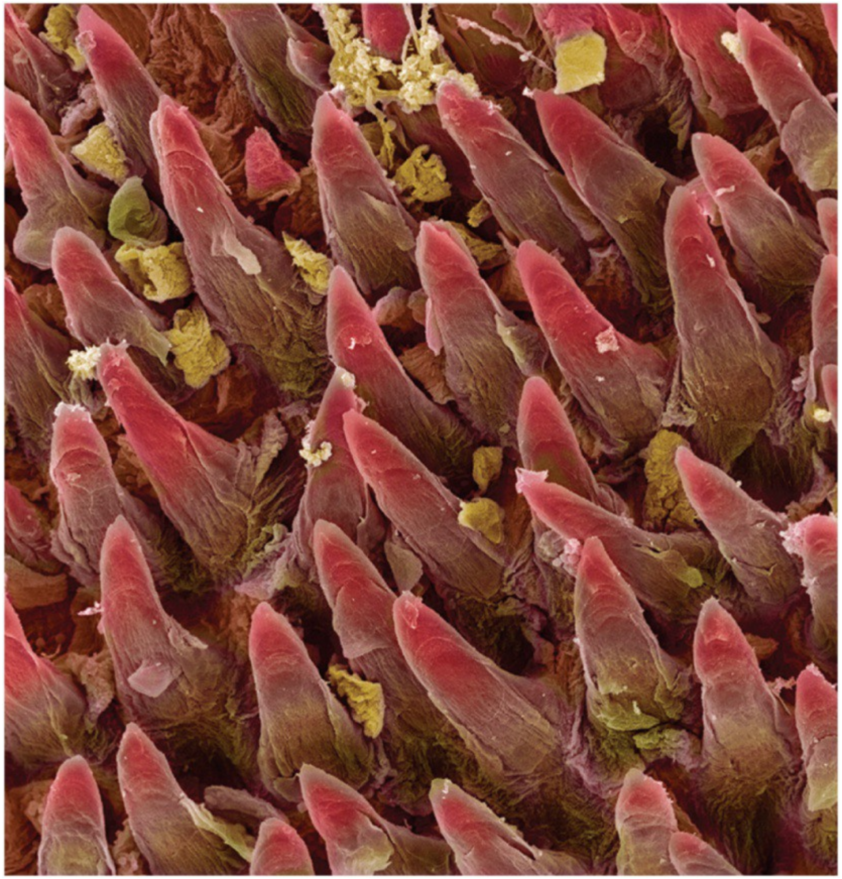
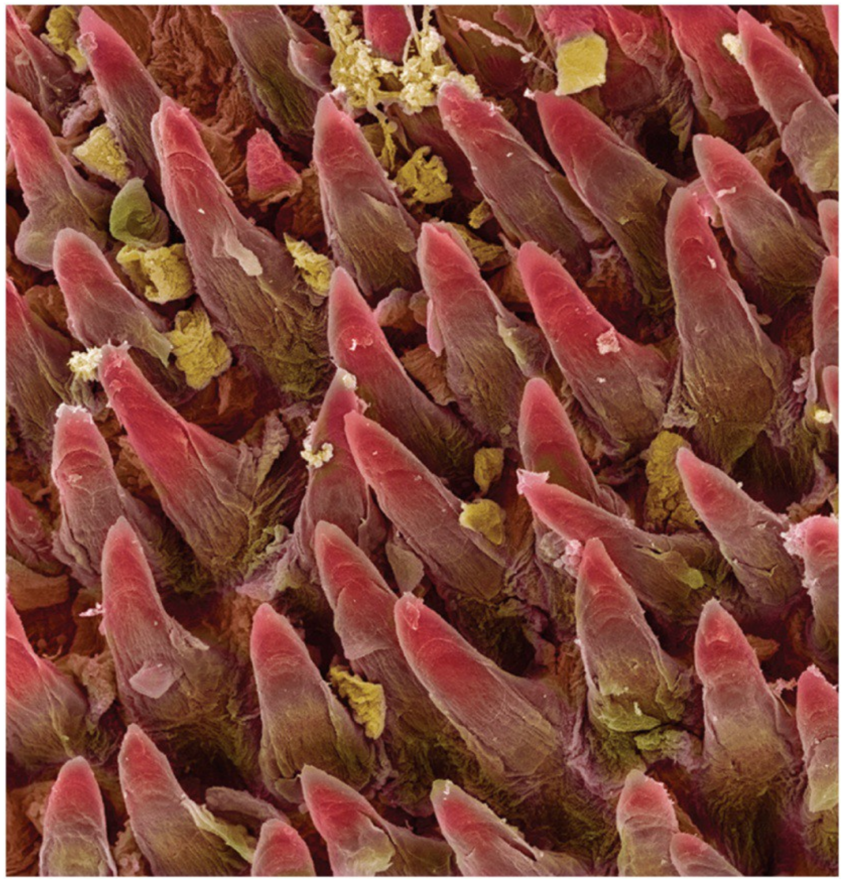
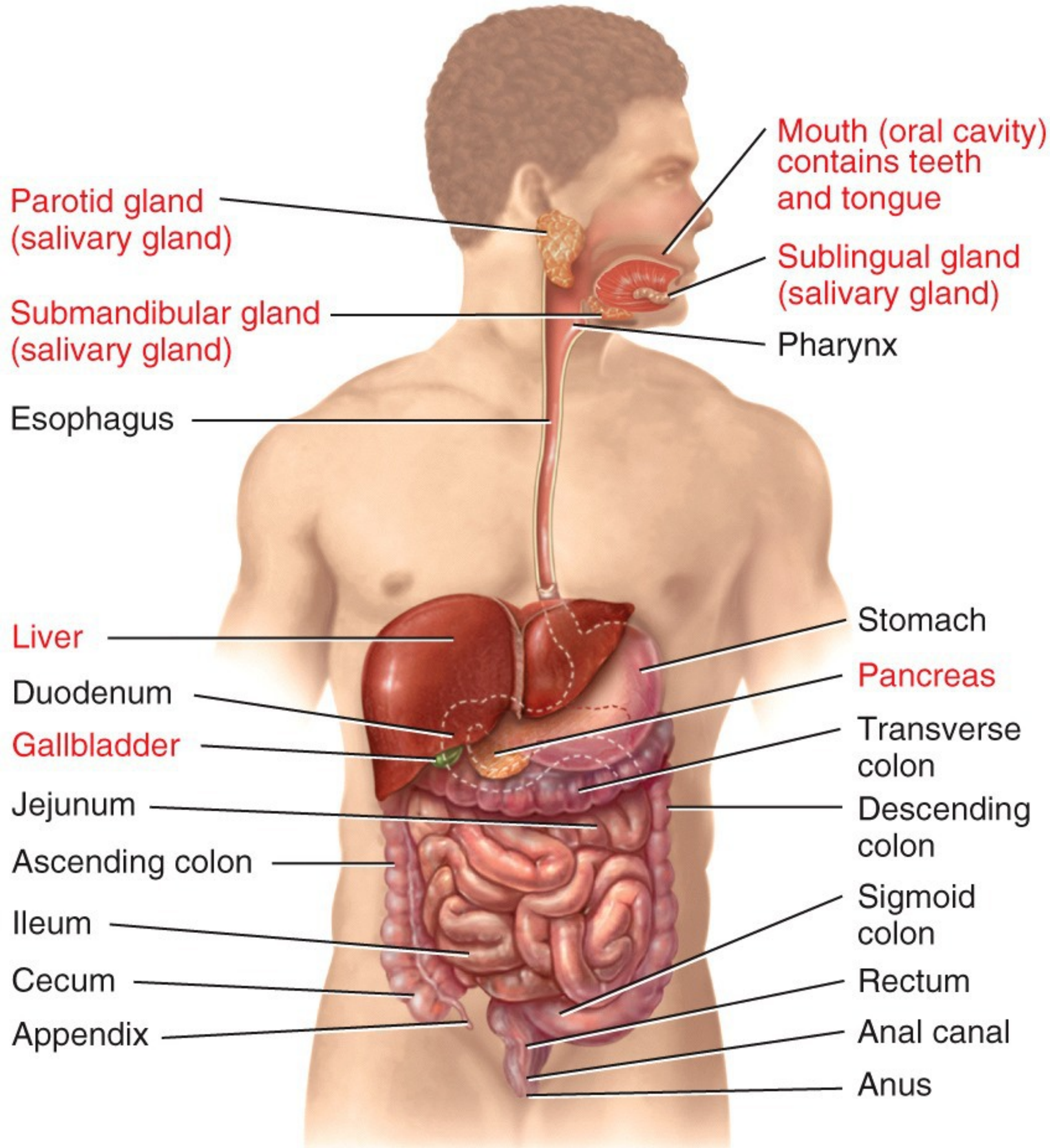
The Digestive System (C25)



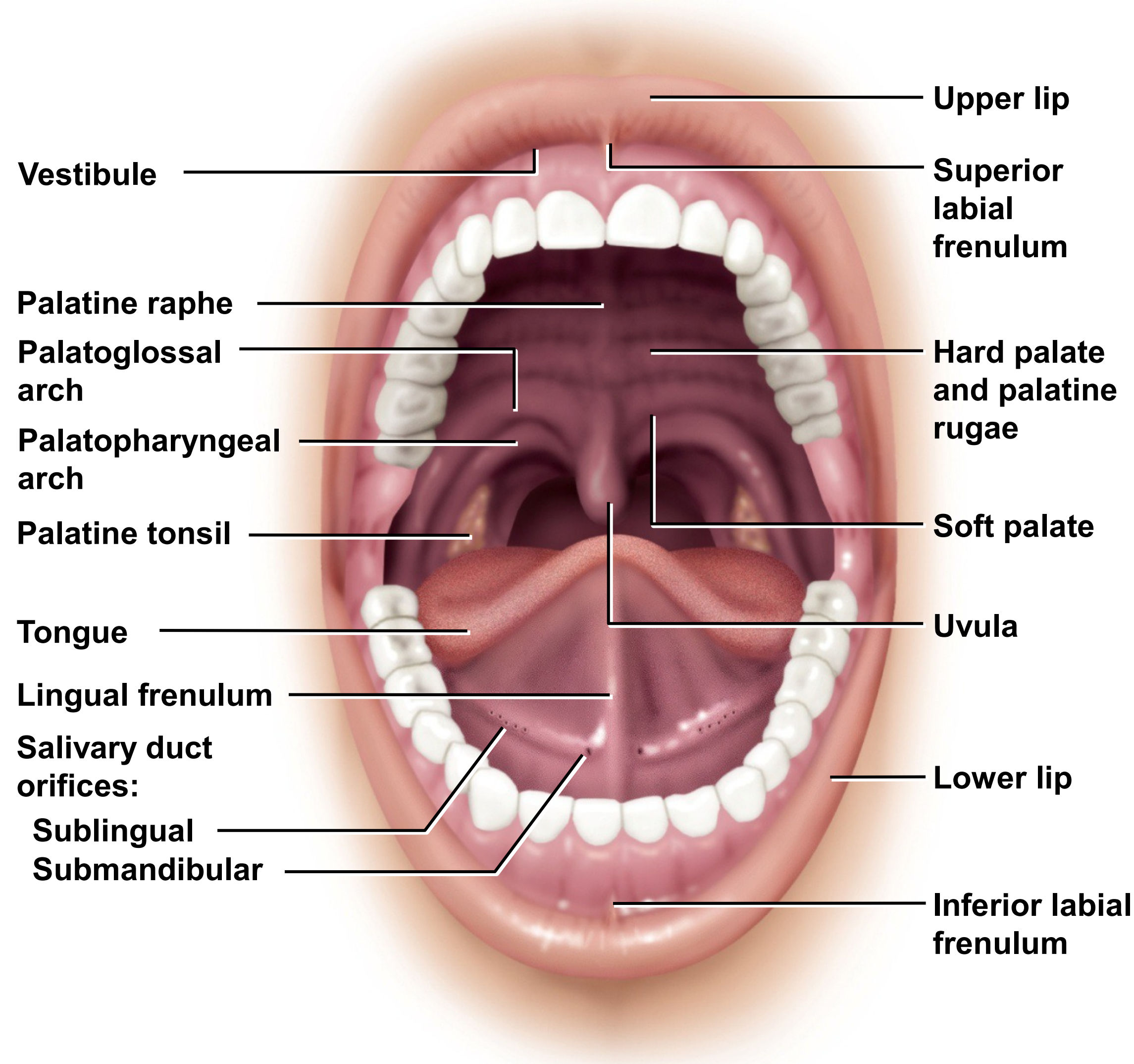
Anatomy of the Digestive System



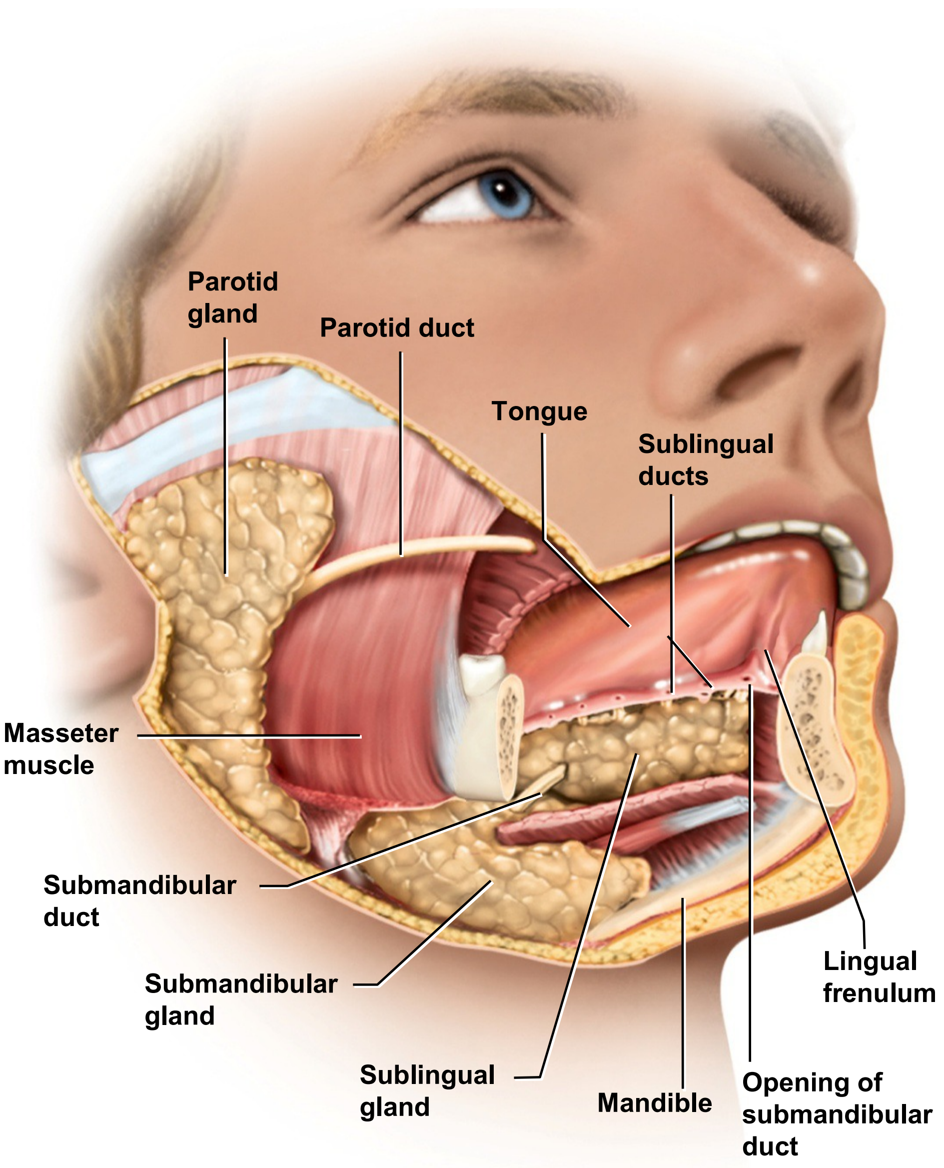


(a) Right lateral view of head and neck and anterior view of trunk

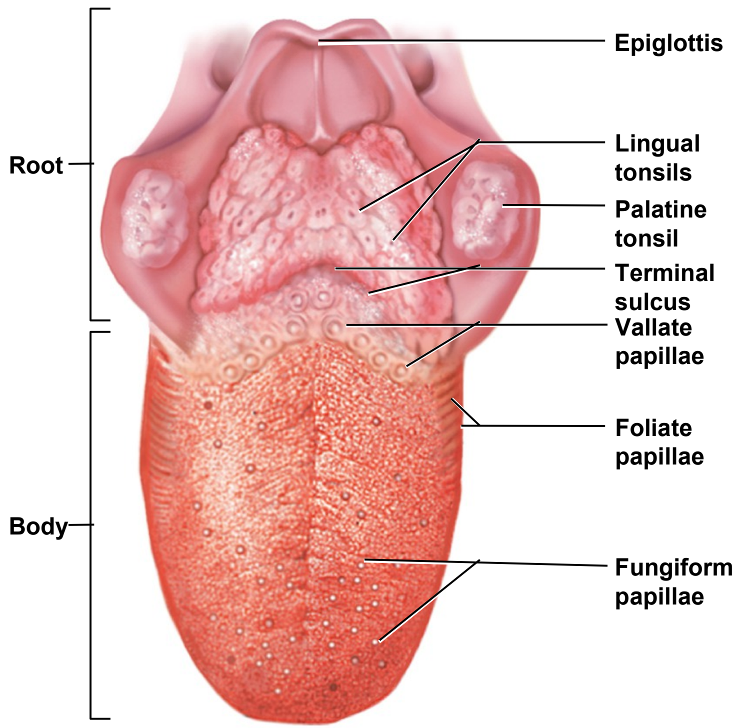
Mouth or Oral Cavity



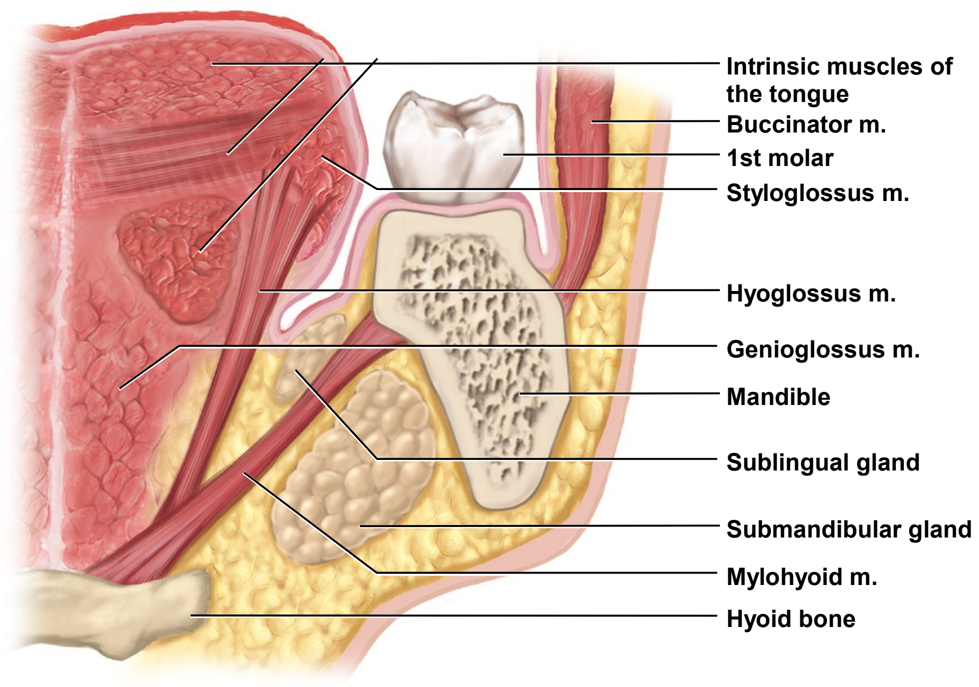
Salivary Glands



Tongue

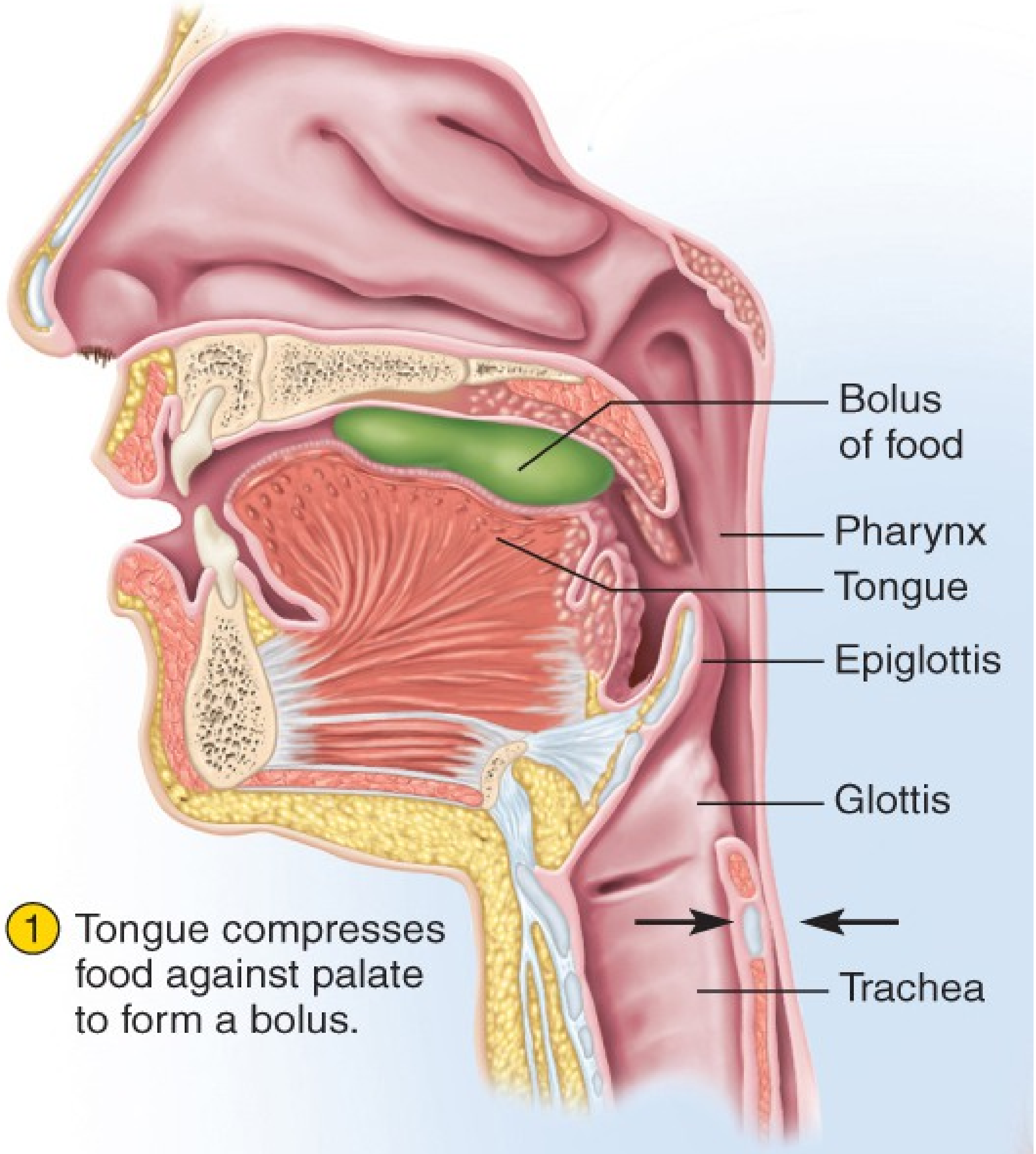


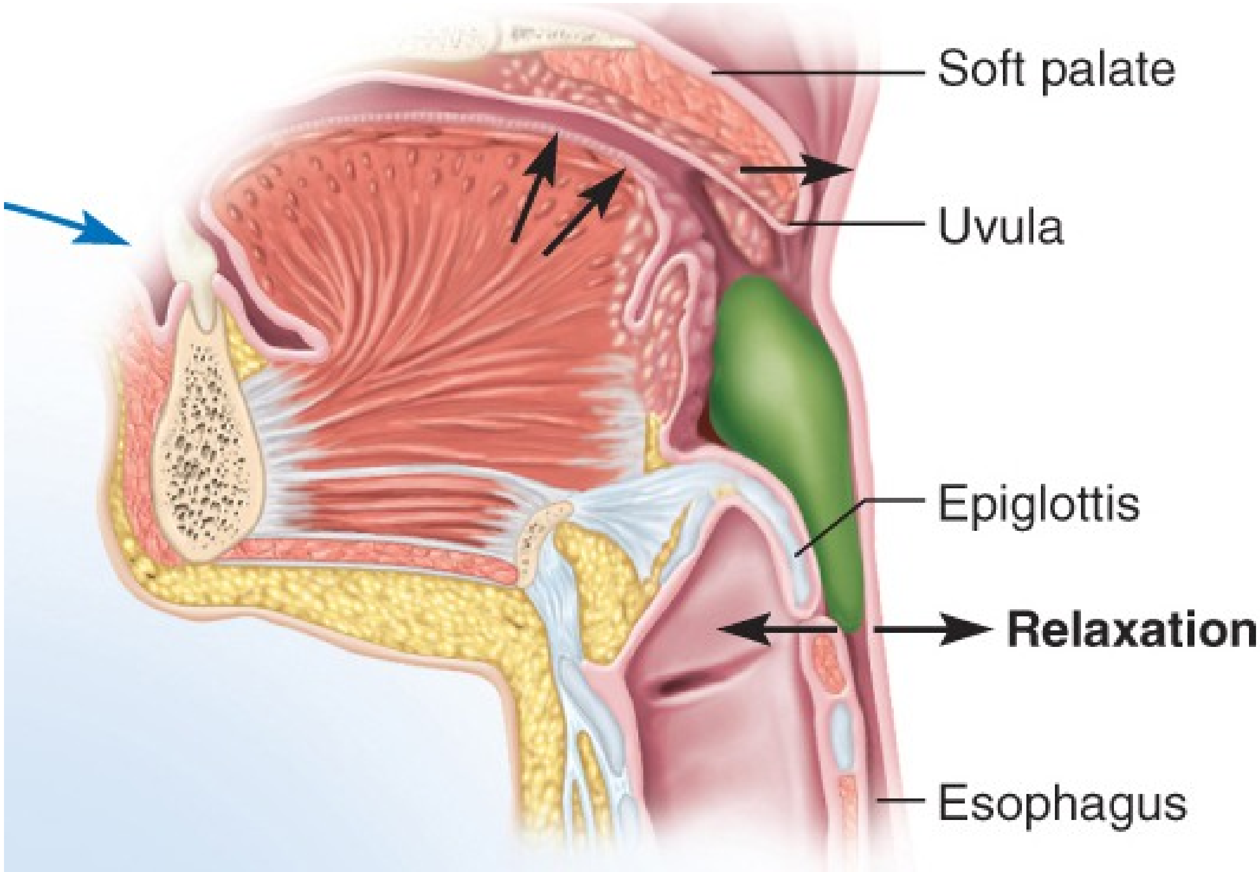
(a) Superior view



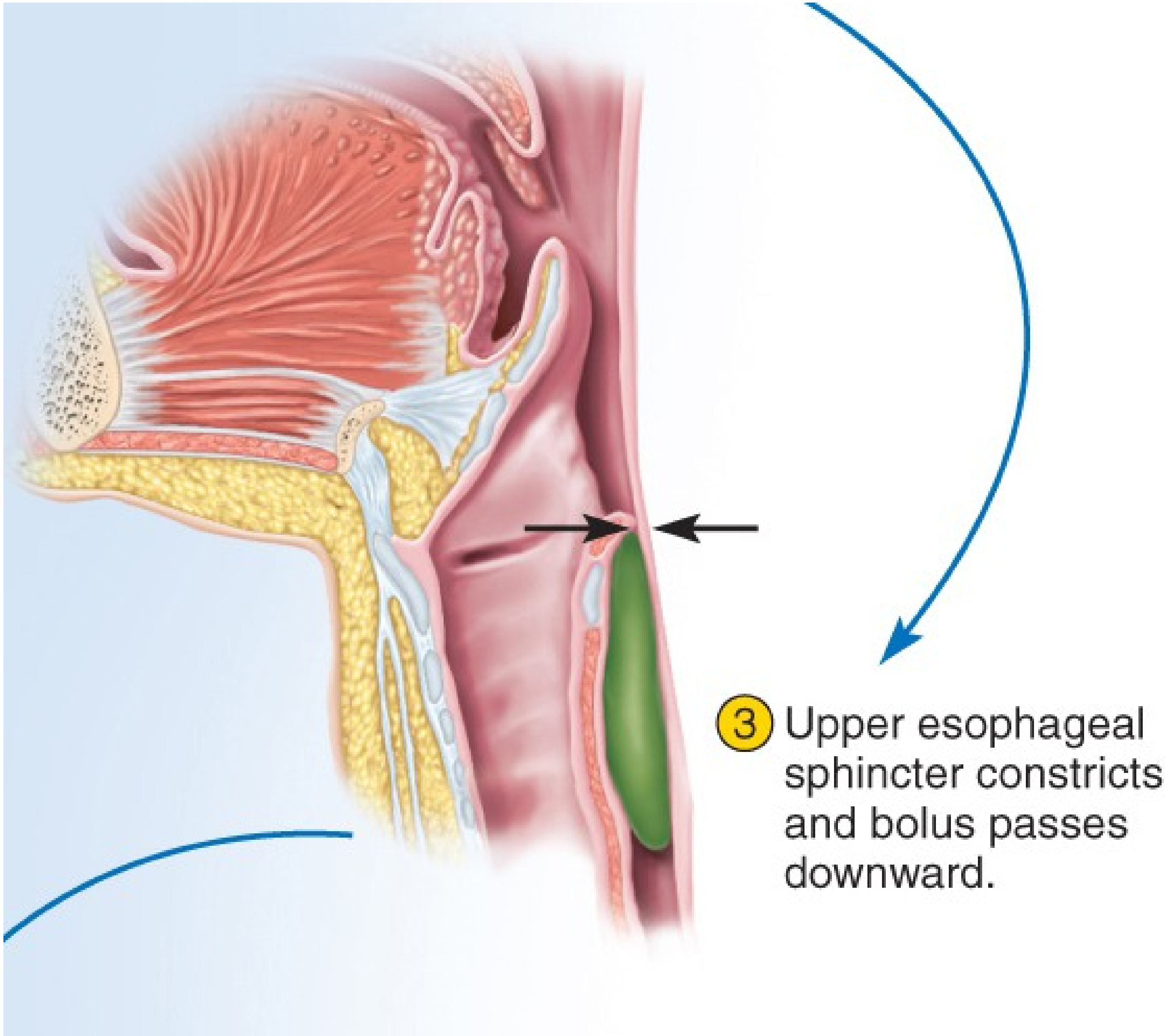
(b) Frontal section, anterior view

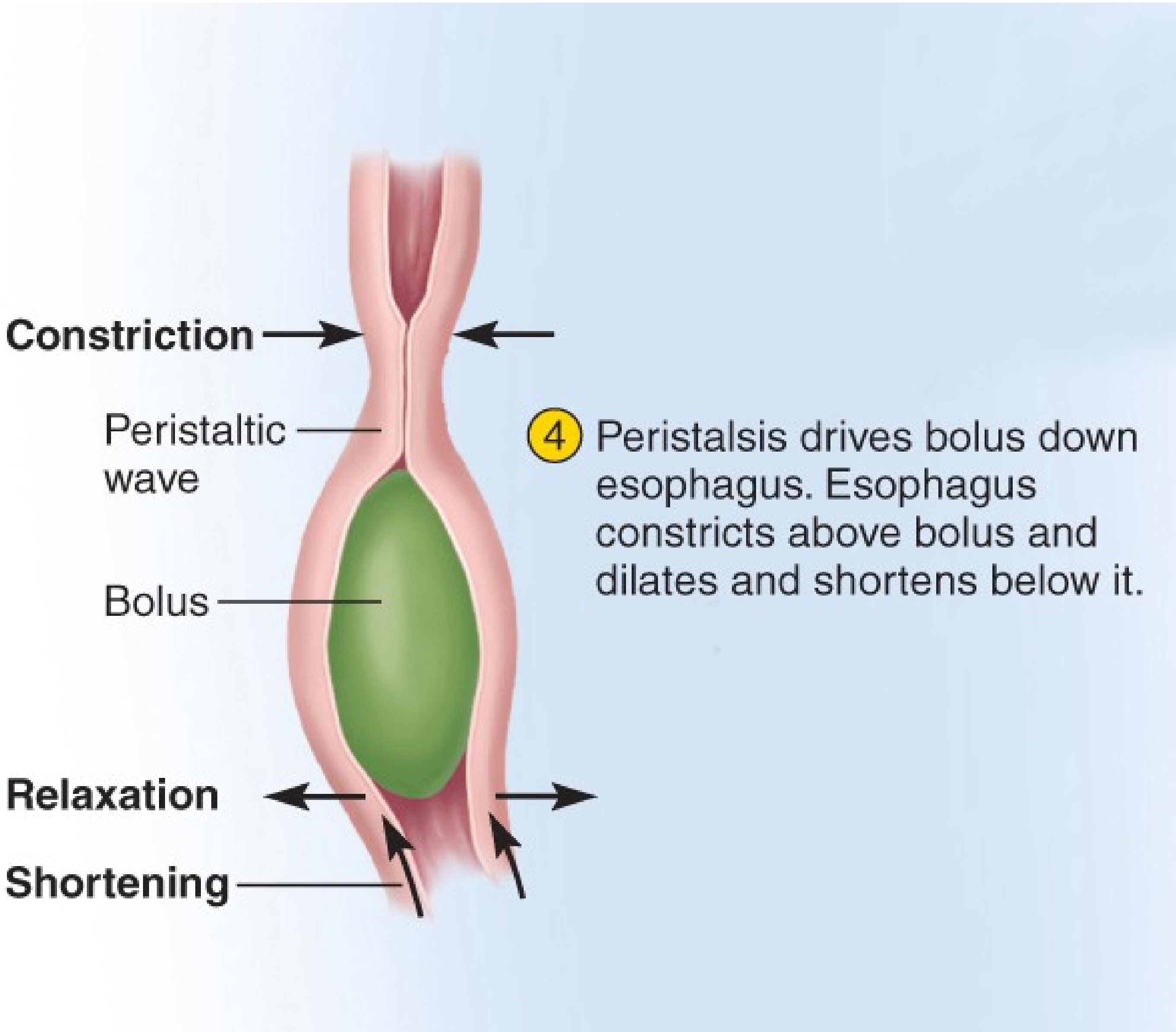
Swallowing occurs in “two phases”

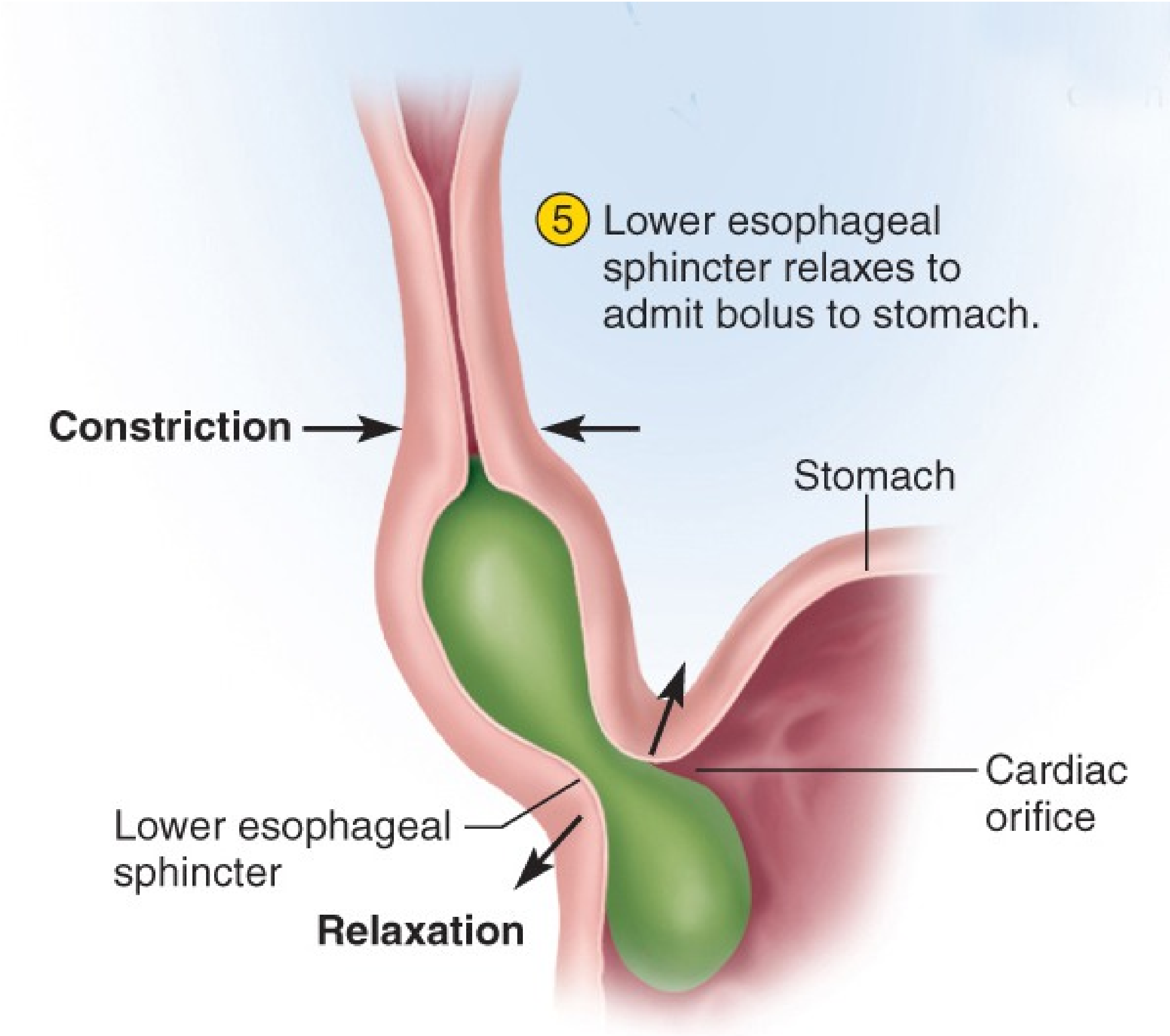


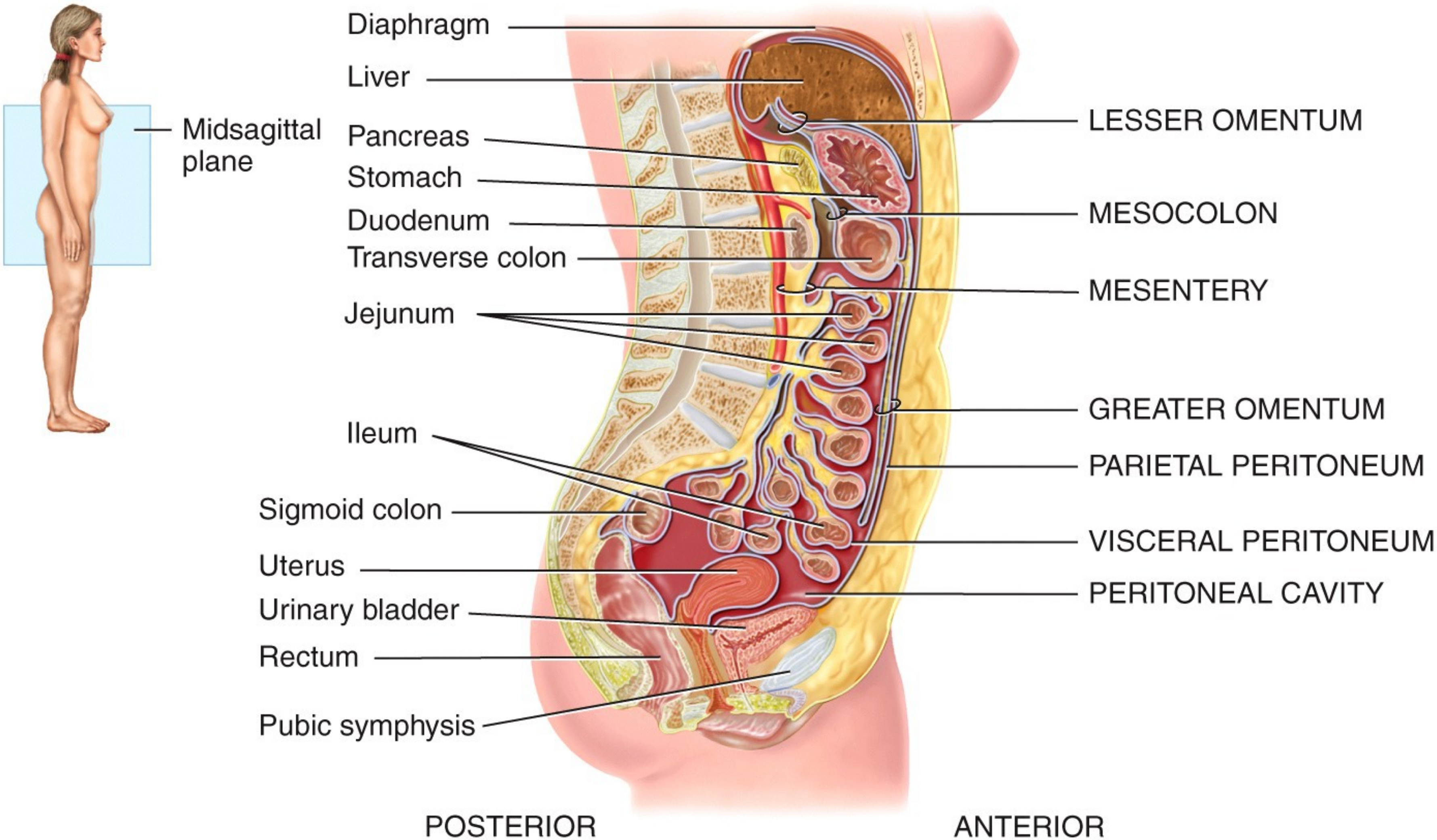


2 Bolus passes into pharynx. Misdirection of bolus is prevented by tongue blocking oral cavity, soft palate blocking nasal cavity, and epiglottis blocking larynx.

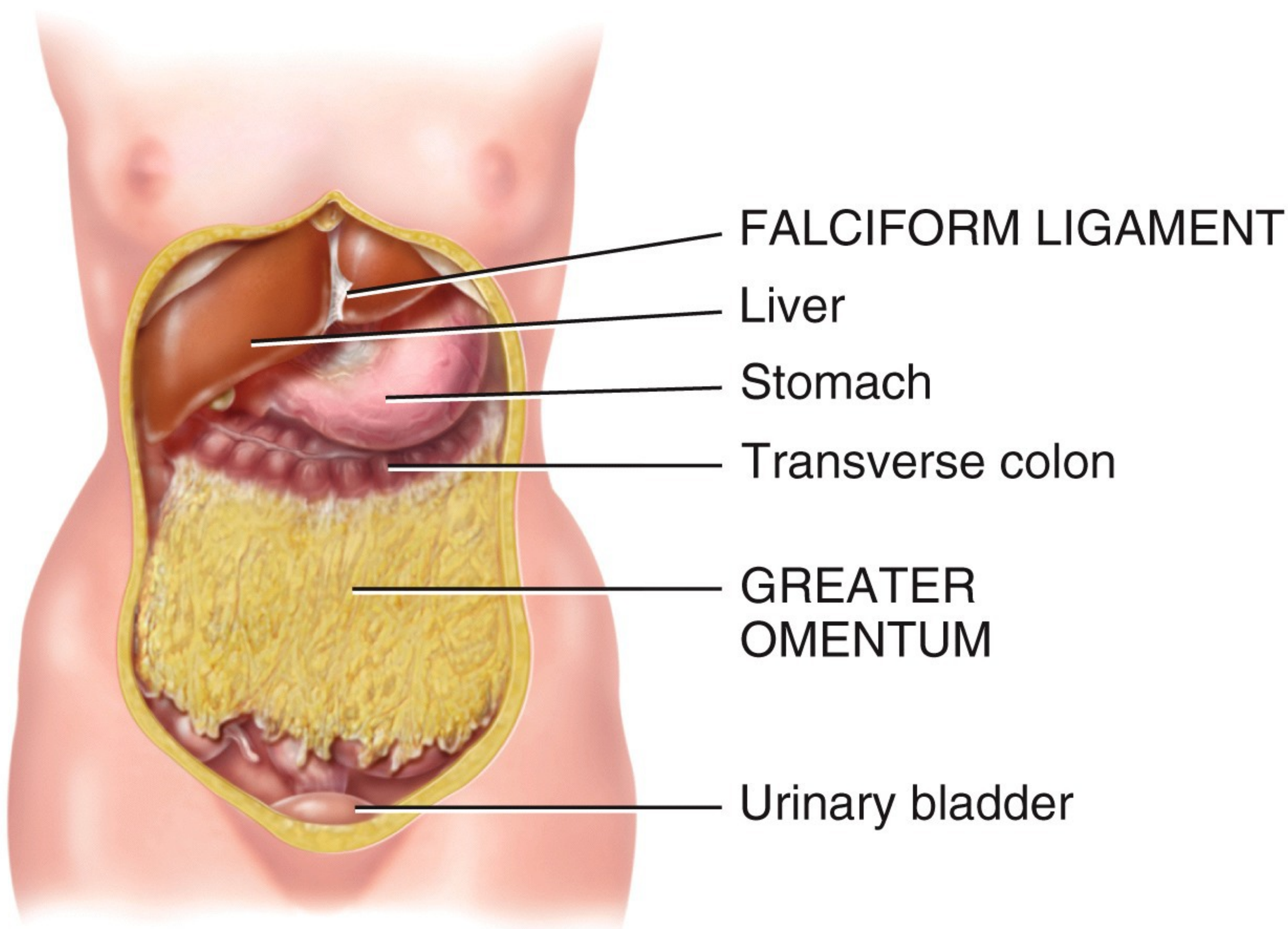

3
Upper esophageal sphincter constricts and bolus passes downward.


Constriction
Peristaltic wave
Bolus
Relaxation
Shortening
4 Peristalsis drives bolus down esophagus. Esophagus constricts above bolus and dilates and shortens below it.

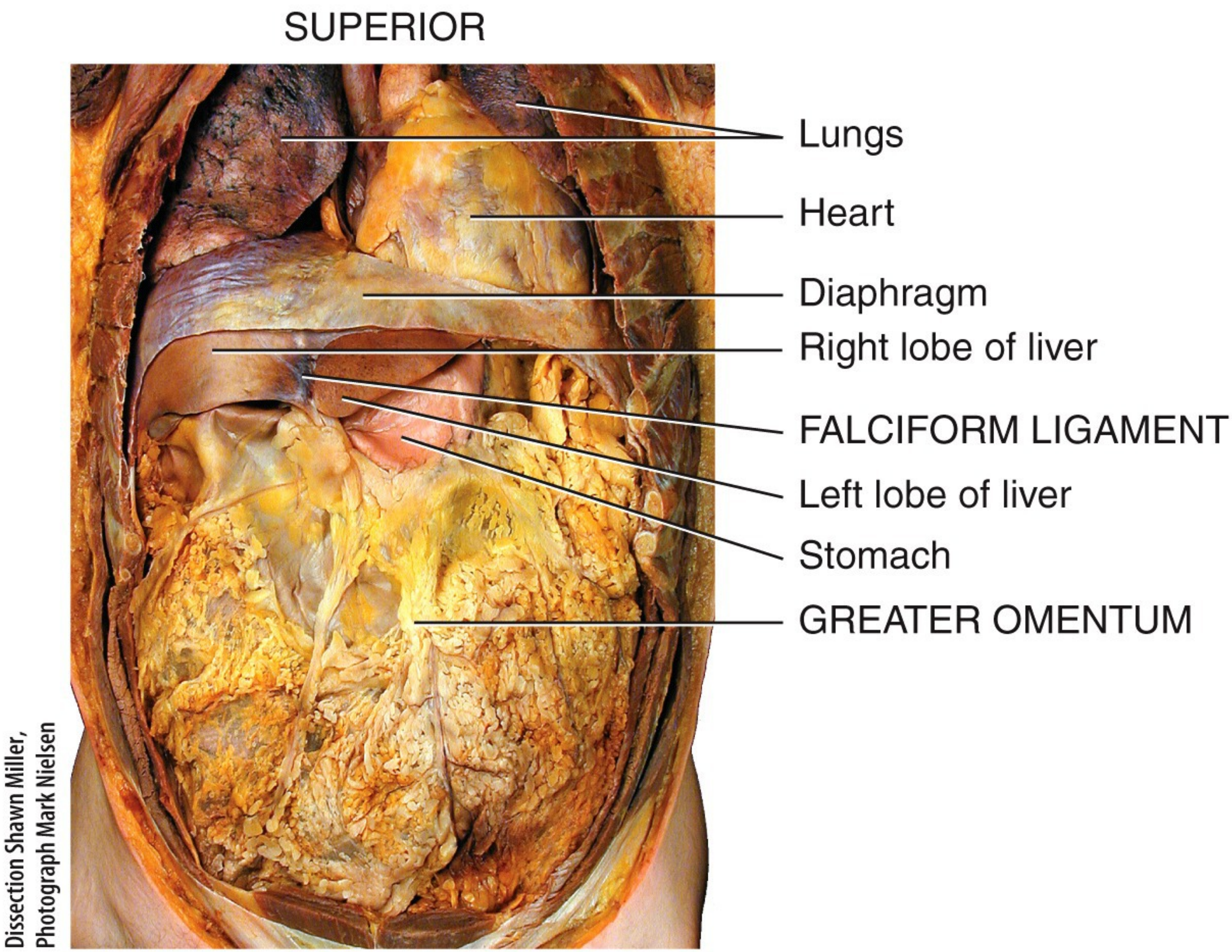

5 Lower esophageal sphincter relaxes to admit bolus to stomach.
Constriction
Stomach
Cardiac orifice
Lower esophageal sphincter
Relaxation



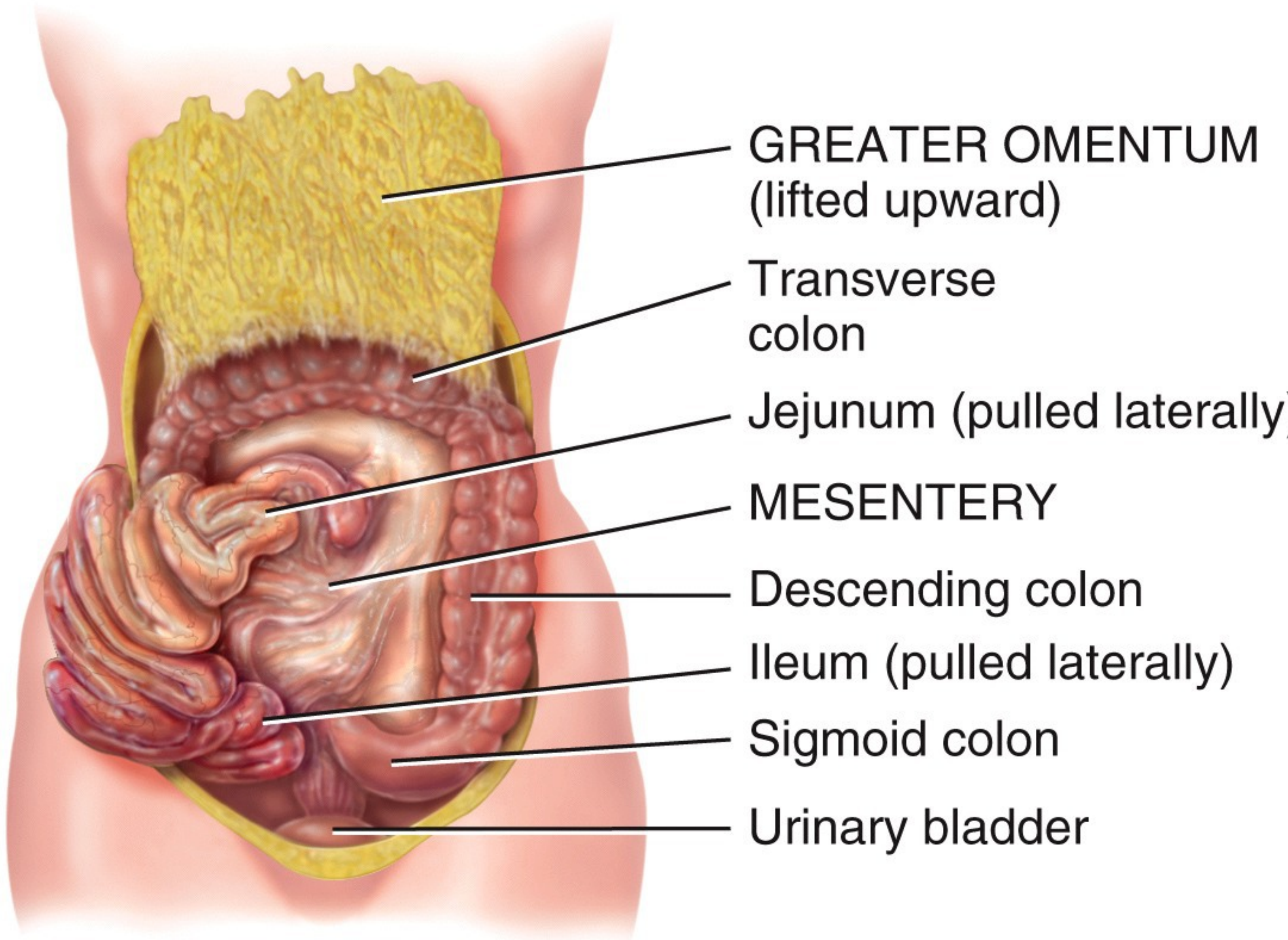
(a) Midsagittal section showing the peritoneal folds



(b) Anterior view



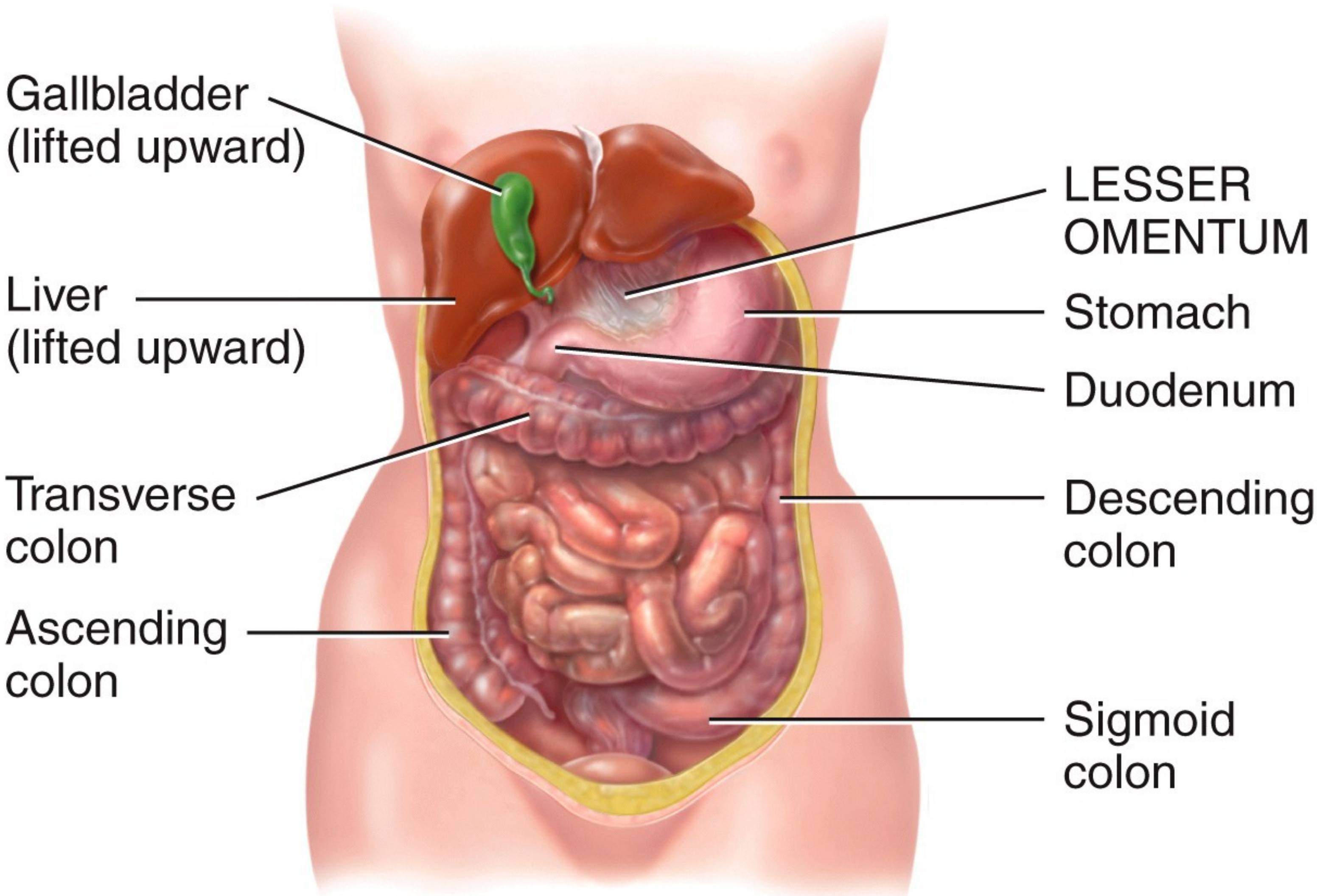
(e) Anterior view



(d) Anterior view (greater omentum lifted and small intestine moved to right side)

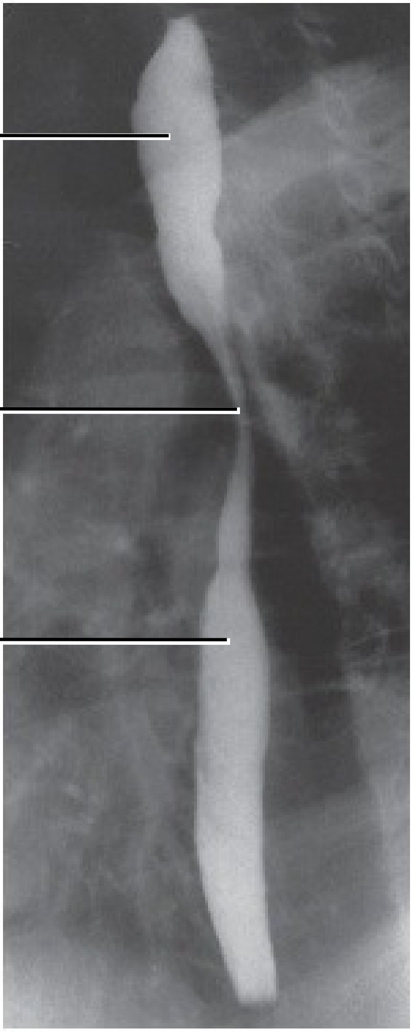
The Classic Beer Belly!

This greater omentum contains approximately
10 gallons of adipose tissue!

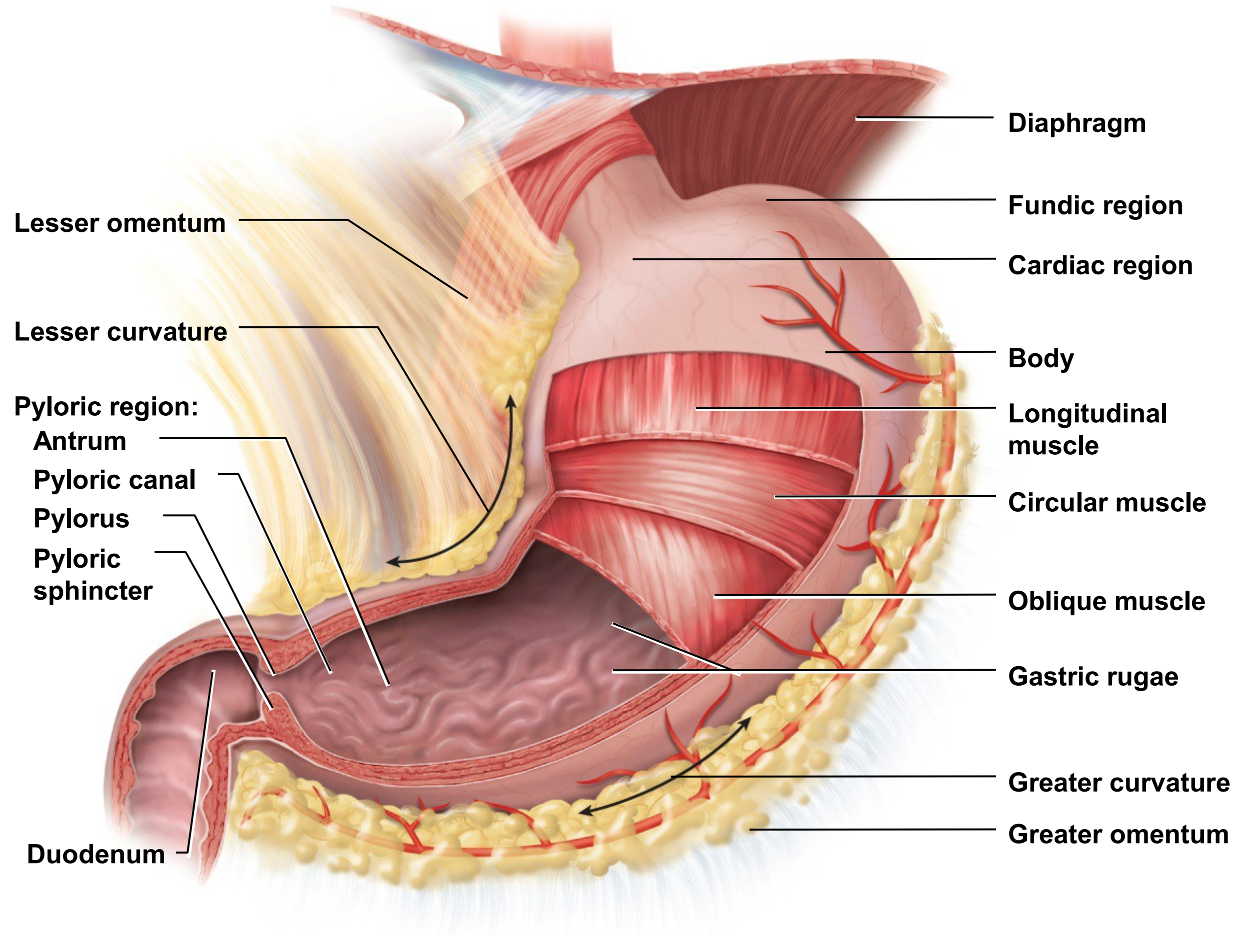


(c) Lesser omentum, anterior view
(liver and gallbladder lifted)

X-ray: Swallowing in Esophagus

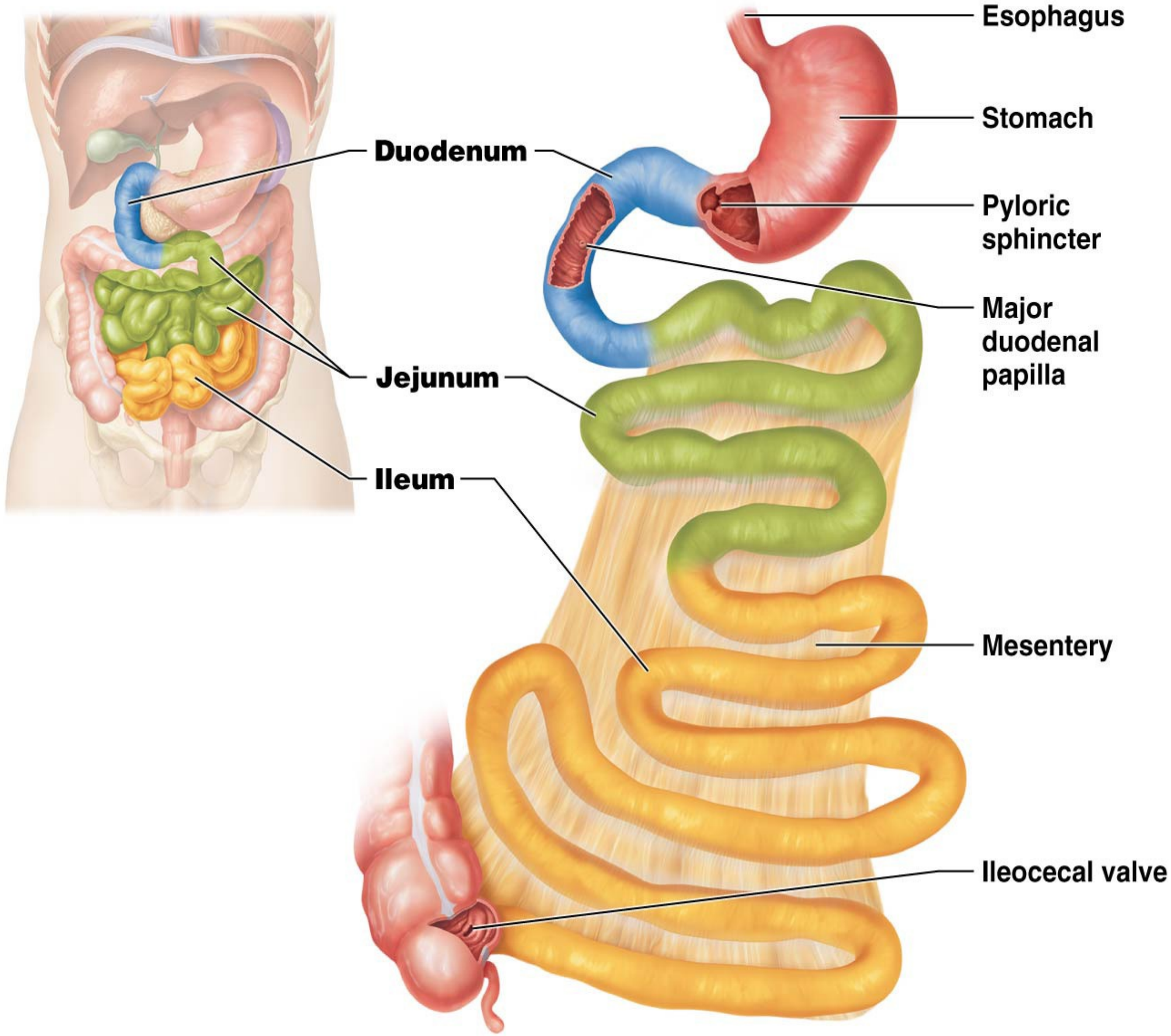


Gross Anatomy of Stomach

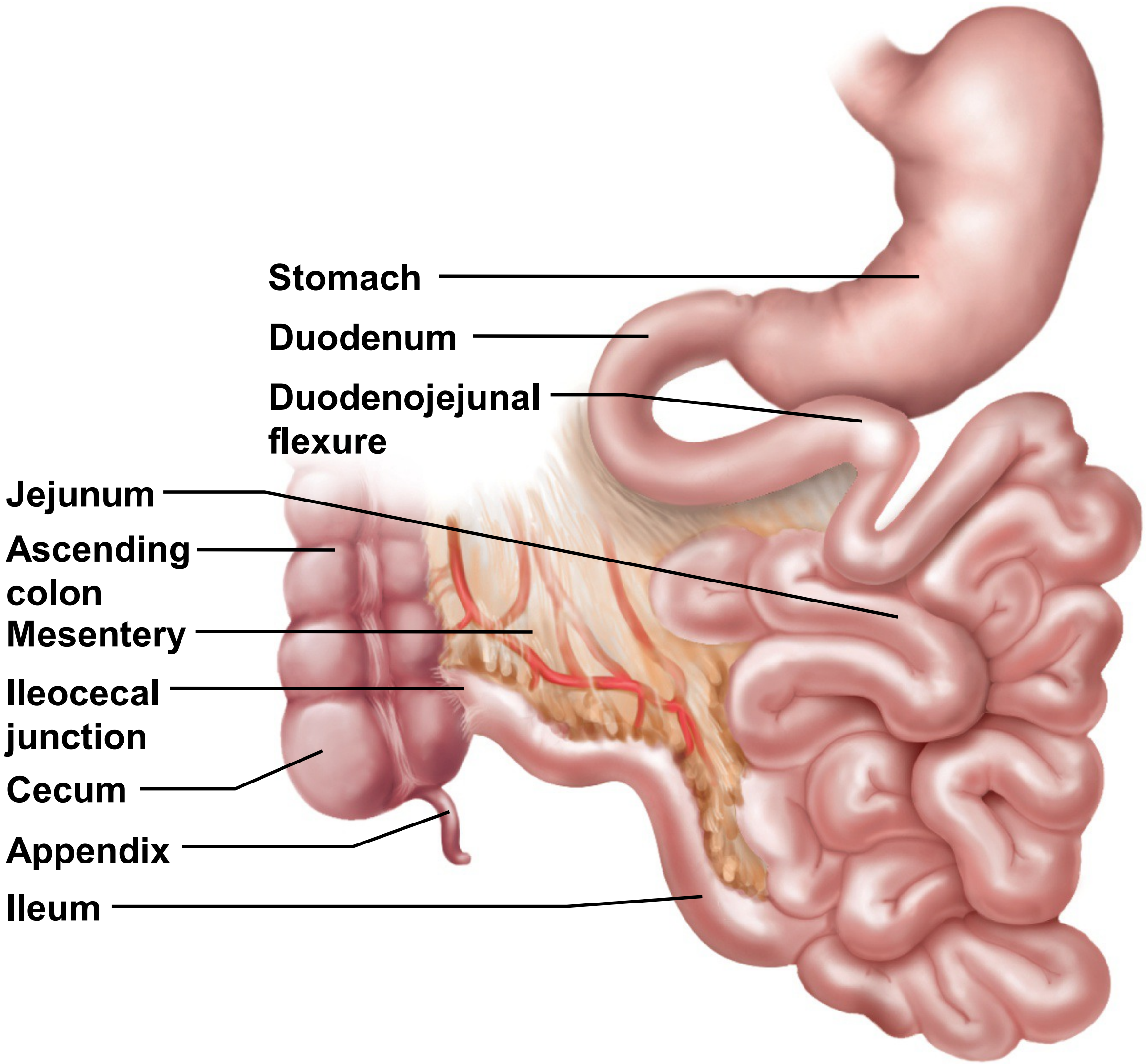


bulge of fundus, narrowing of pyloric region, thickness of pyloric sphincter, and greater and lesser curvatures

Gross anatomy of the small intestine.

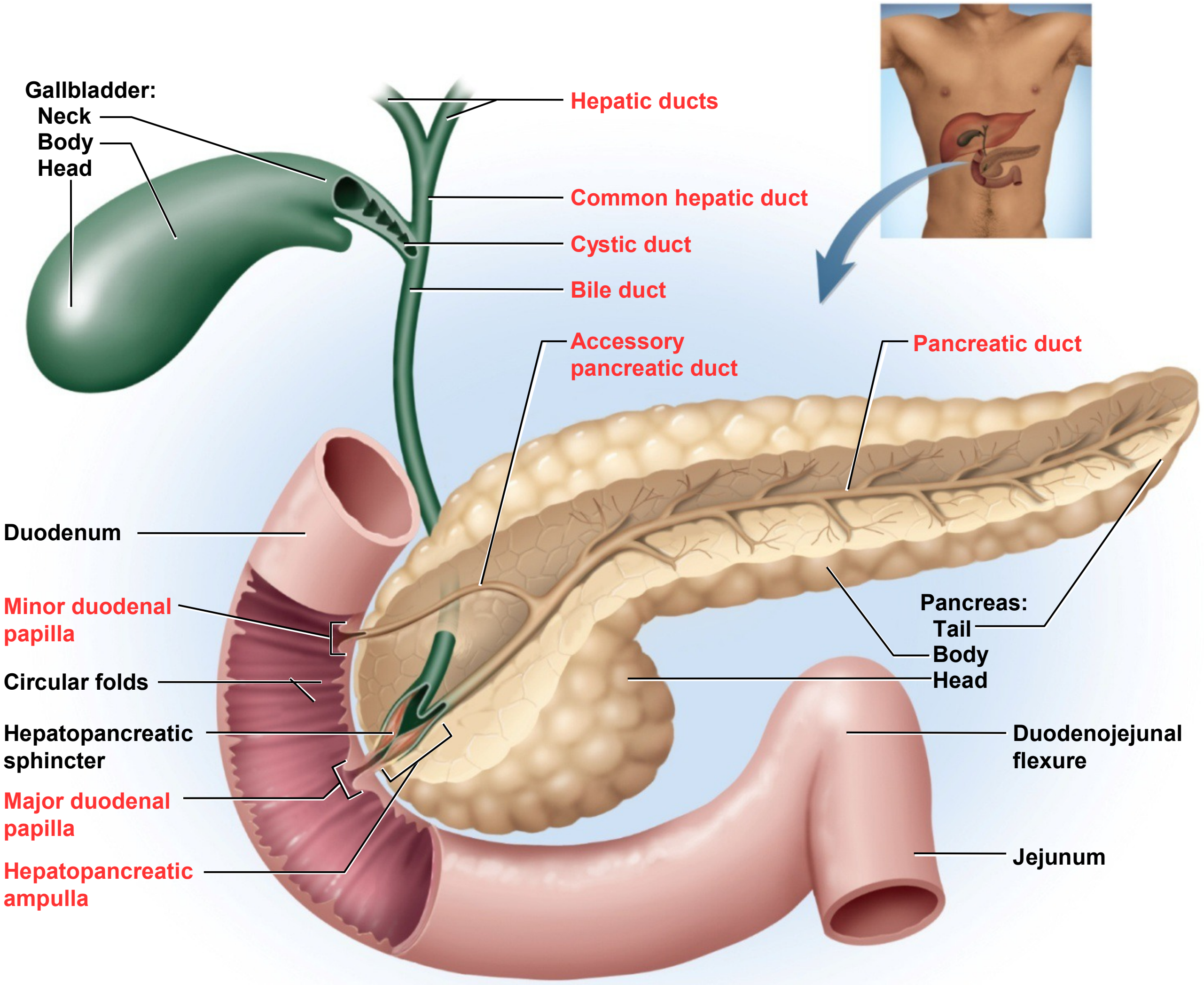


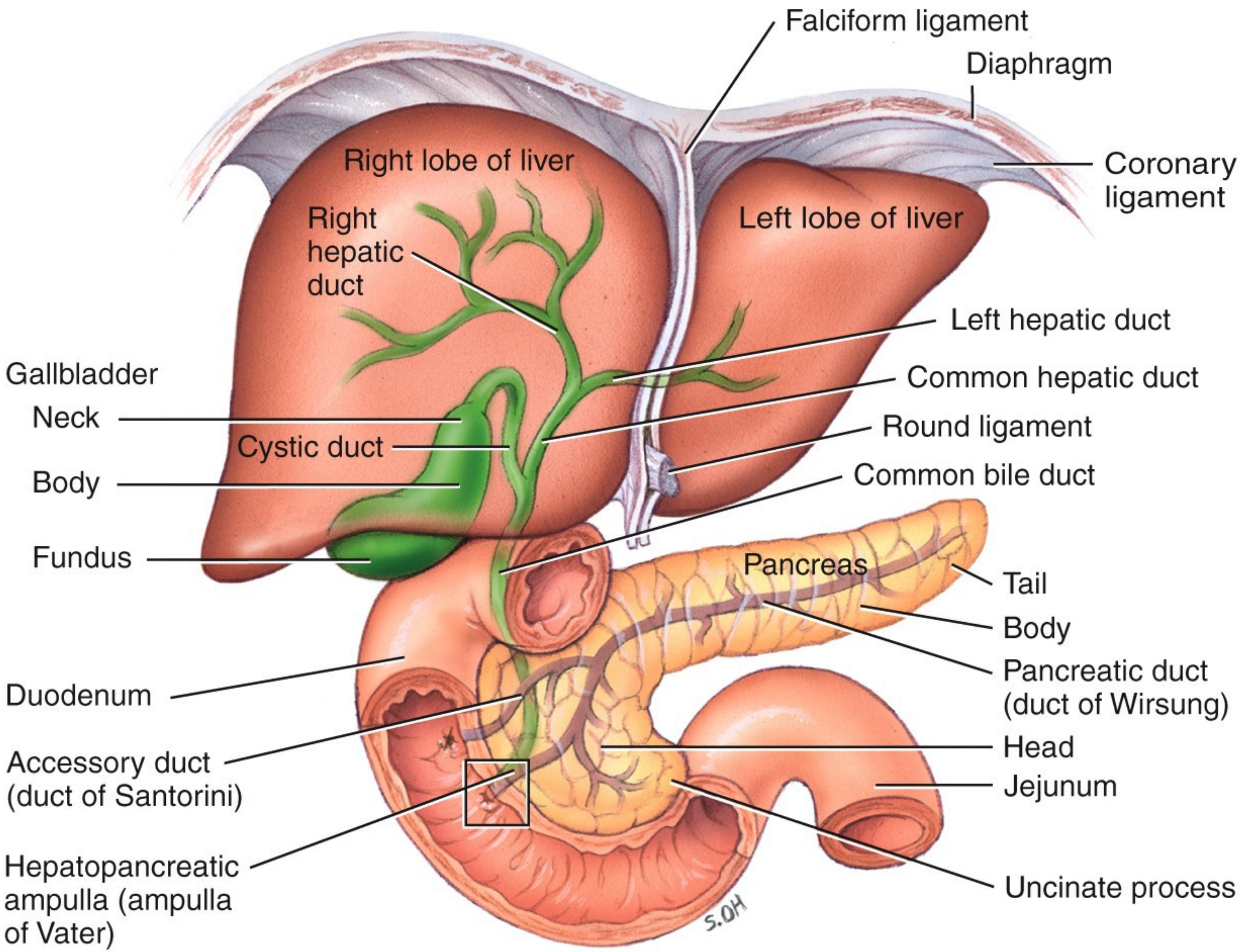
Small Intestine



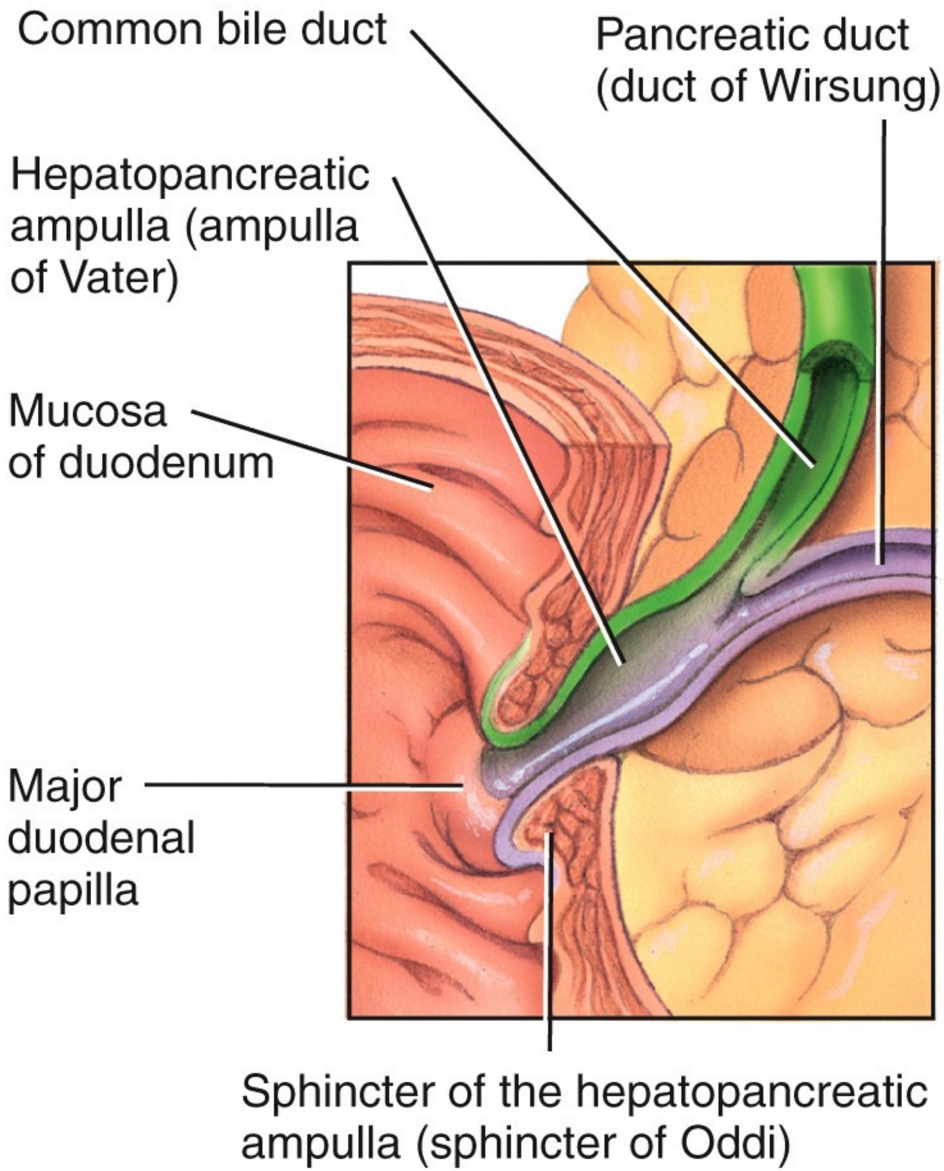
Coiled mass filling most of the abdominal cavity inferior to the stomach and the liver

Gross Anatomy of the Gallbladder, Pancreas, and Bile Passages

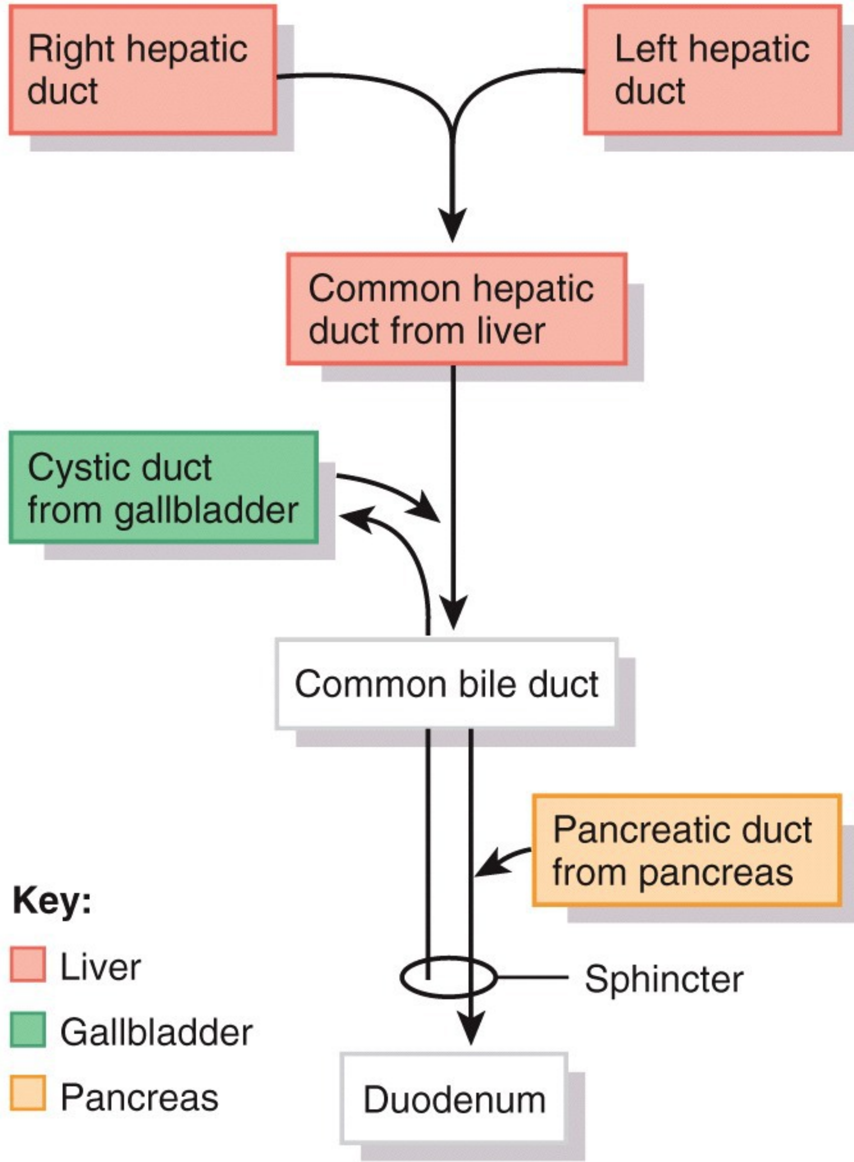




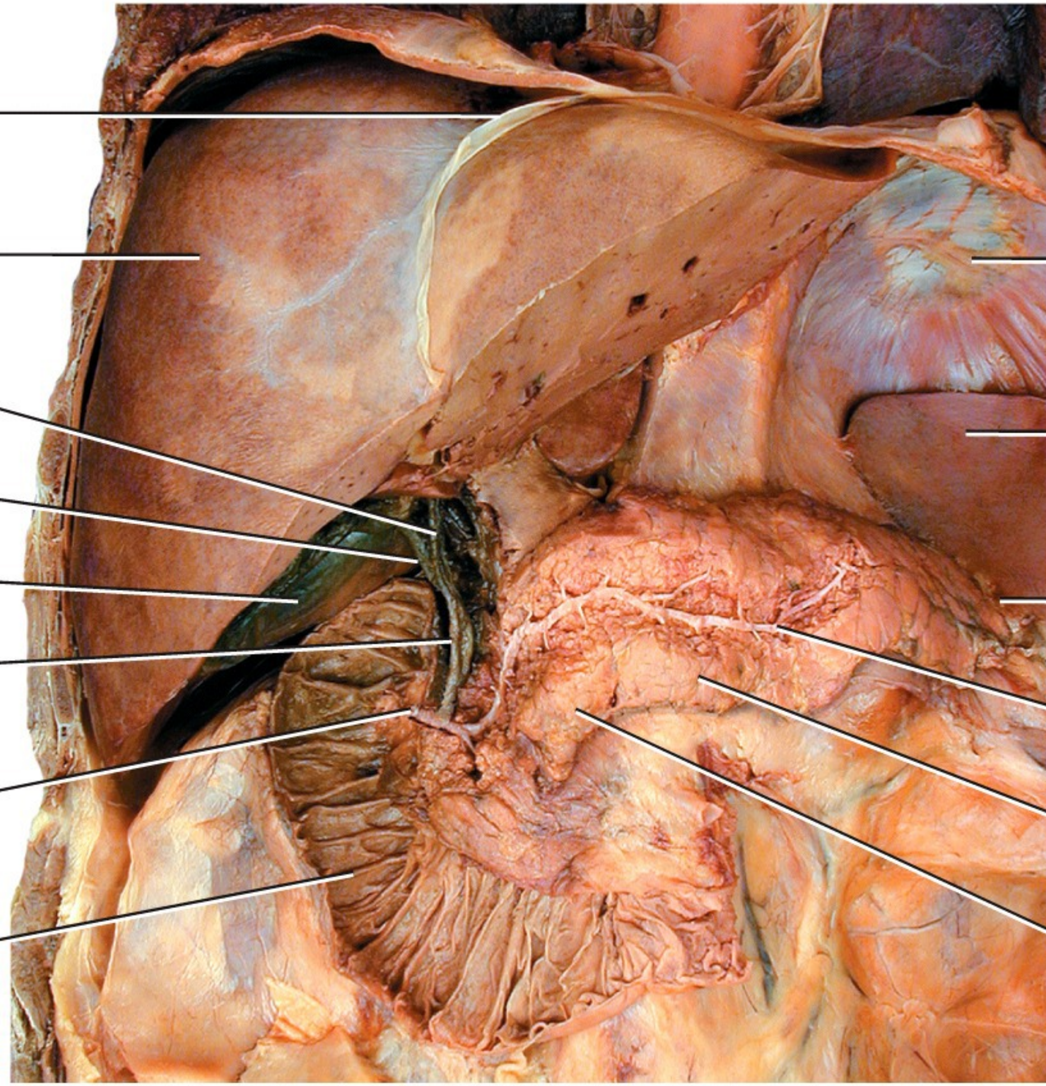
(a) Anterior view



(b) Details of hepatopancreatic ampulla



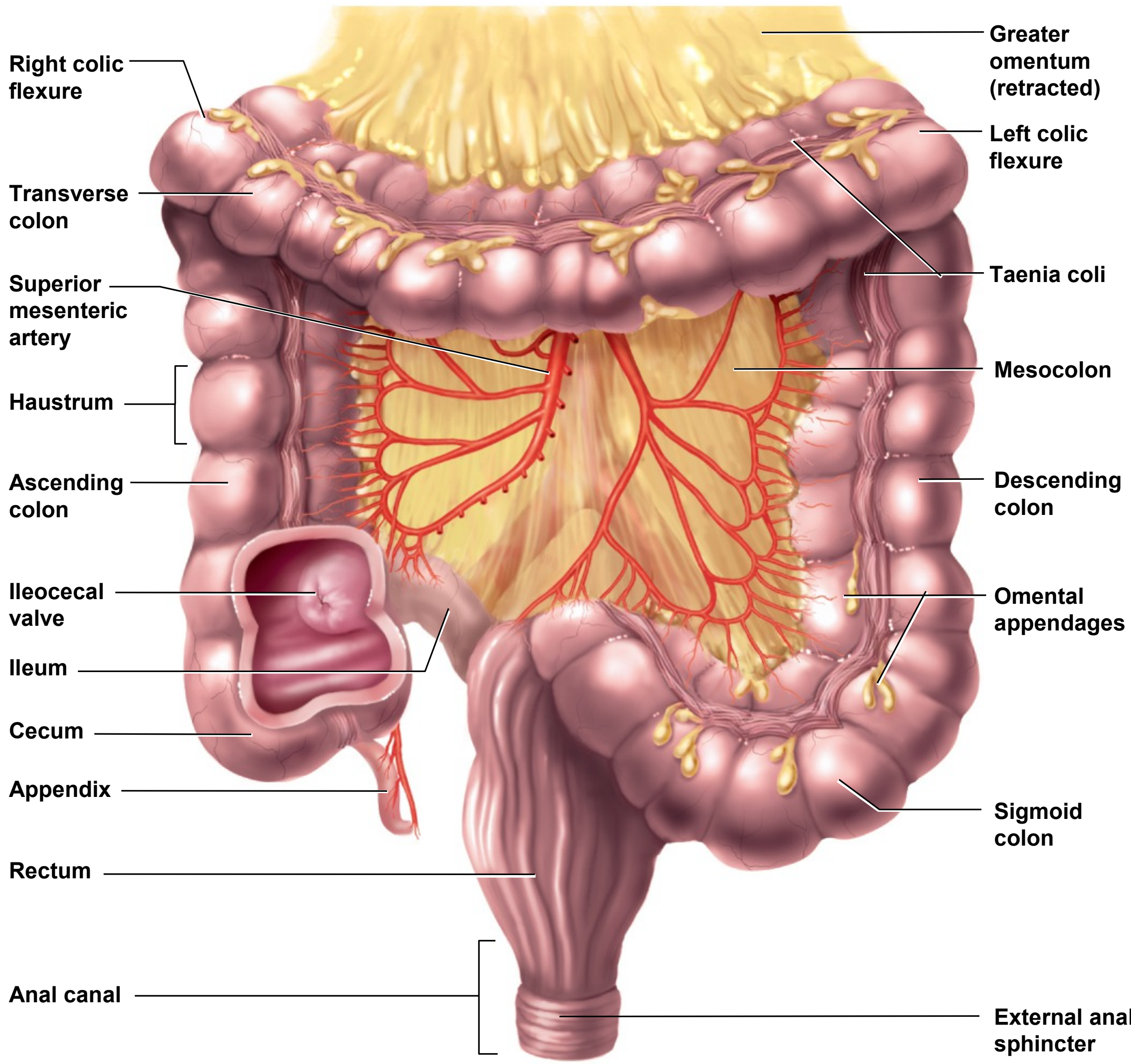
(c) Ducts carrying bile from liver and gallbladder and pancreatic juice from pancreas to the duodenum



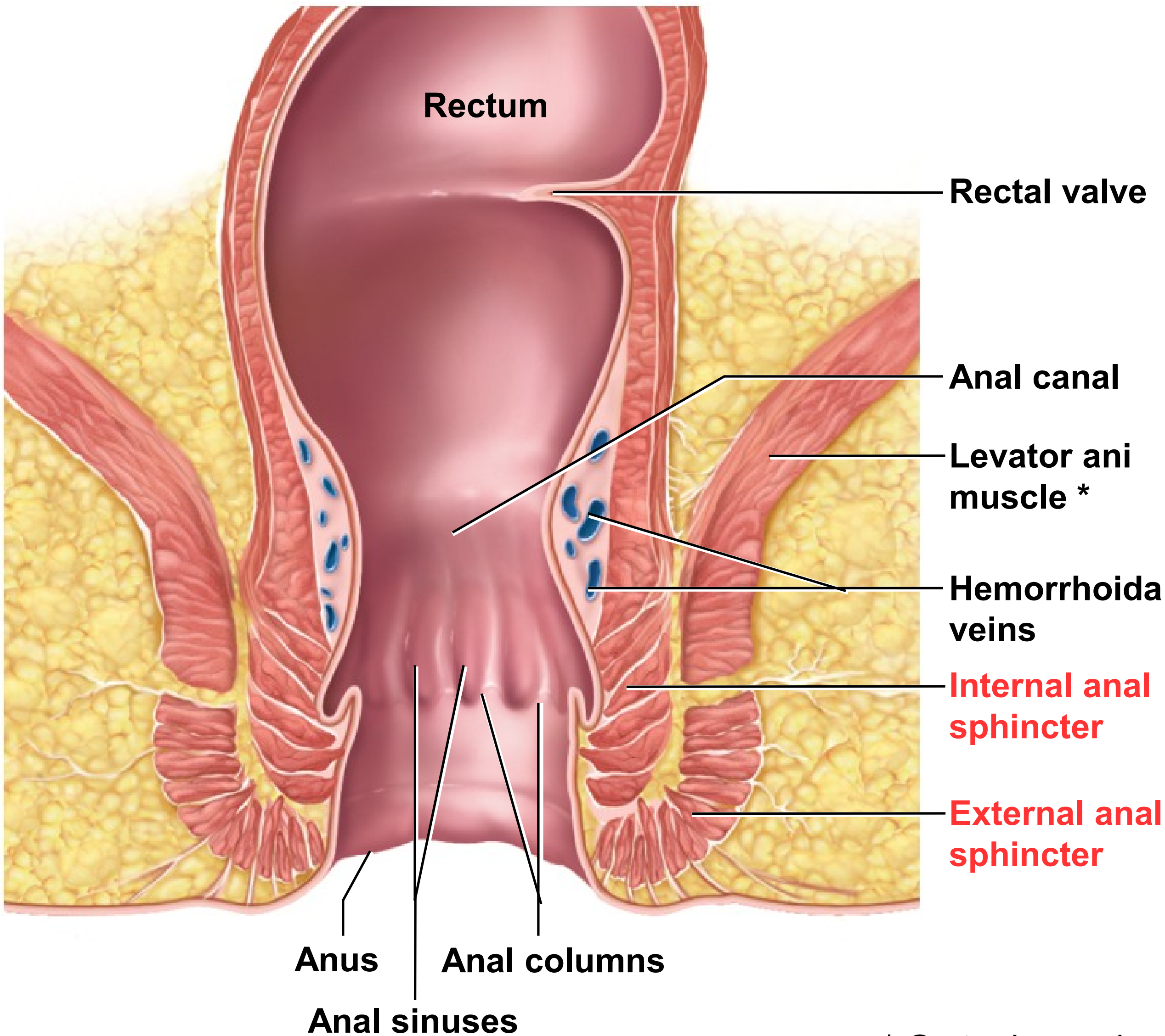
Dissection Shawn Miller, Photograph Mark Nielsen

(d) Anterior view

Anatomy of Large Intestine

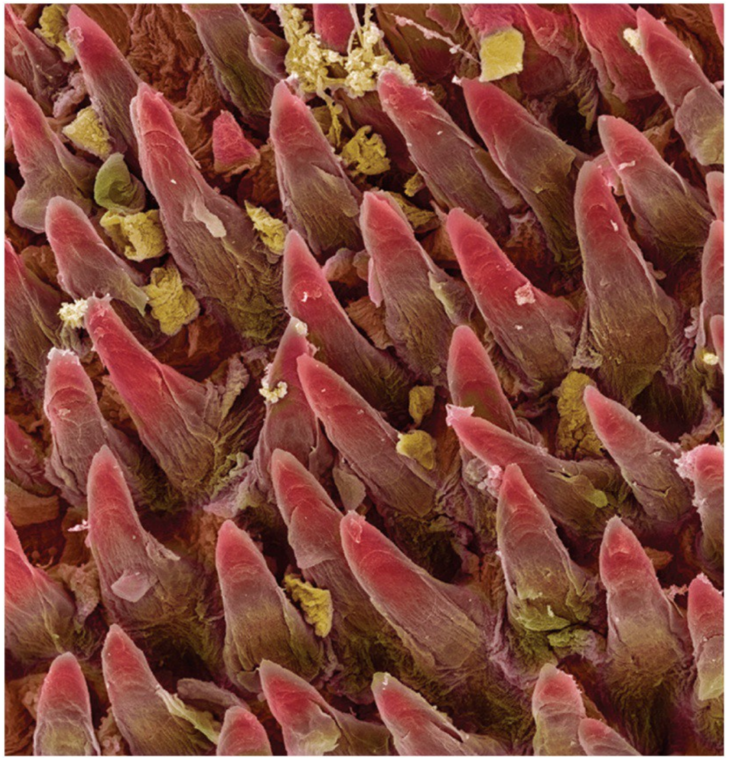


Anatomy of Anal Canal



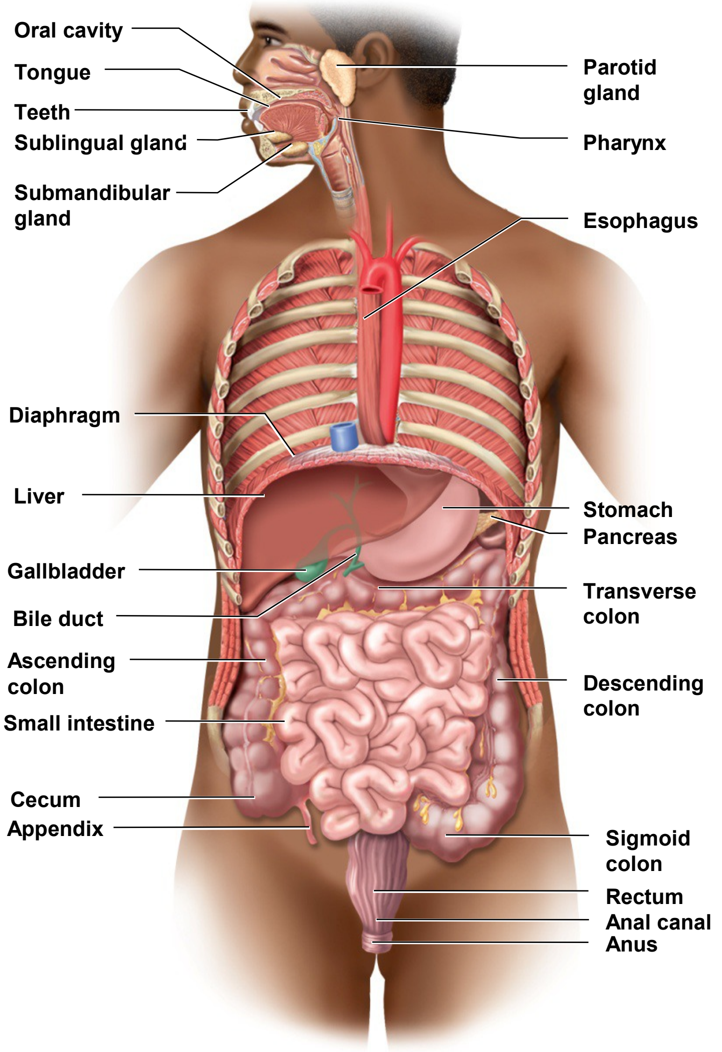
* Go to dog park and watch a dog deficate to see this muscle's function!

Functions of the Digestive System



General Anatomy of the Digestive System

- Two anatomical divisions
- Digestive tract (alimentary canal)
  - 30 foot long muscular tube extending from mouth to anus
  - mouth, pharynx, esophagus, stomach, small intestine, and large intestine
  - gastrointestinal (GI) tract is the stomach and intestines
- Accessory organs
  - teeth, tongue, salivary glands, liver, gallbladder, and pancreas



General Anatomy of the Digestive System

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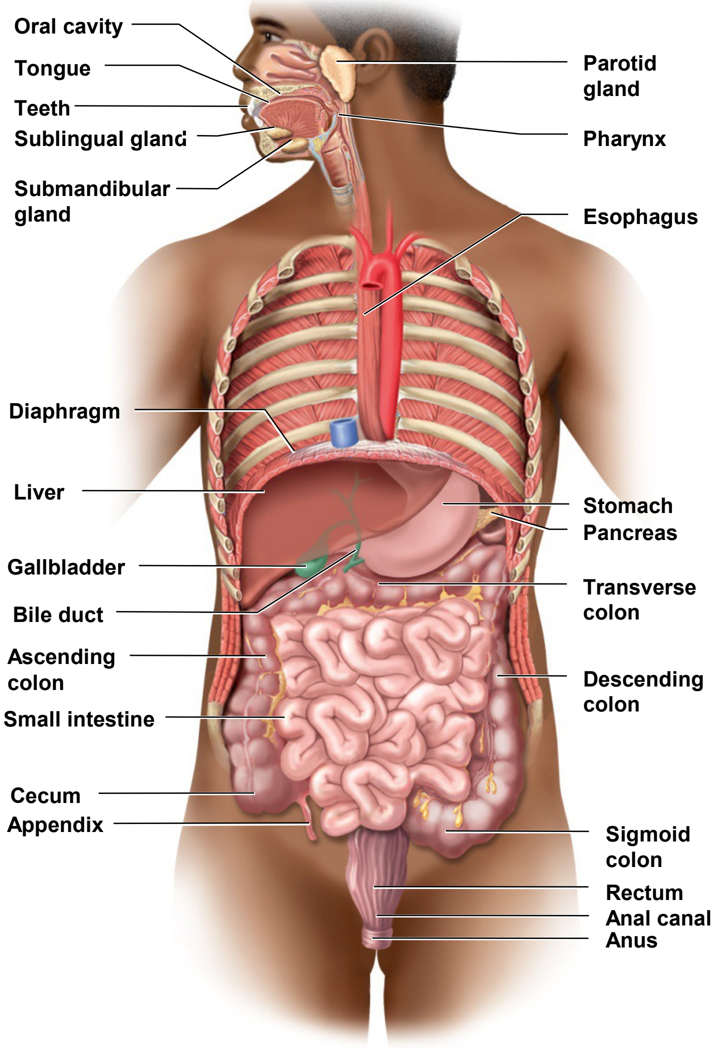


Digestive System Functions

Five functions

ingestion - selective intake of food

digestion – mechanical and chemical breakdown of food into a form usable by the body

absorption - uptake of nutrient molecules into the epithelial cells of the digestive tract and then into the blood and/or lymph (crossing mucosa)

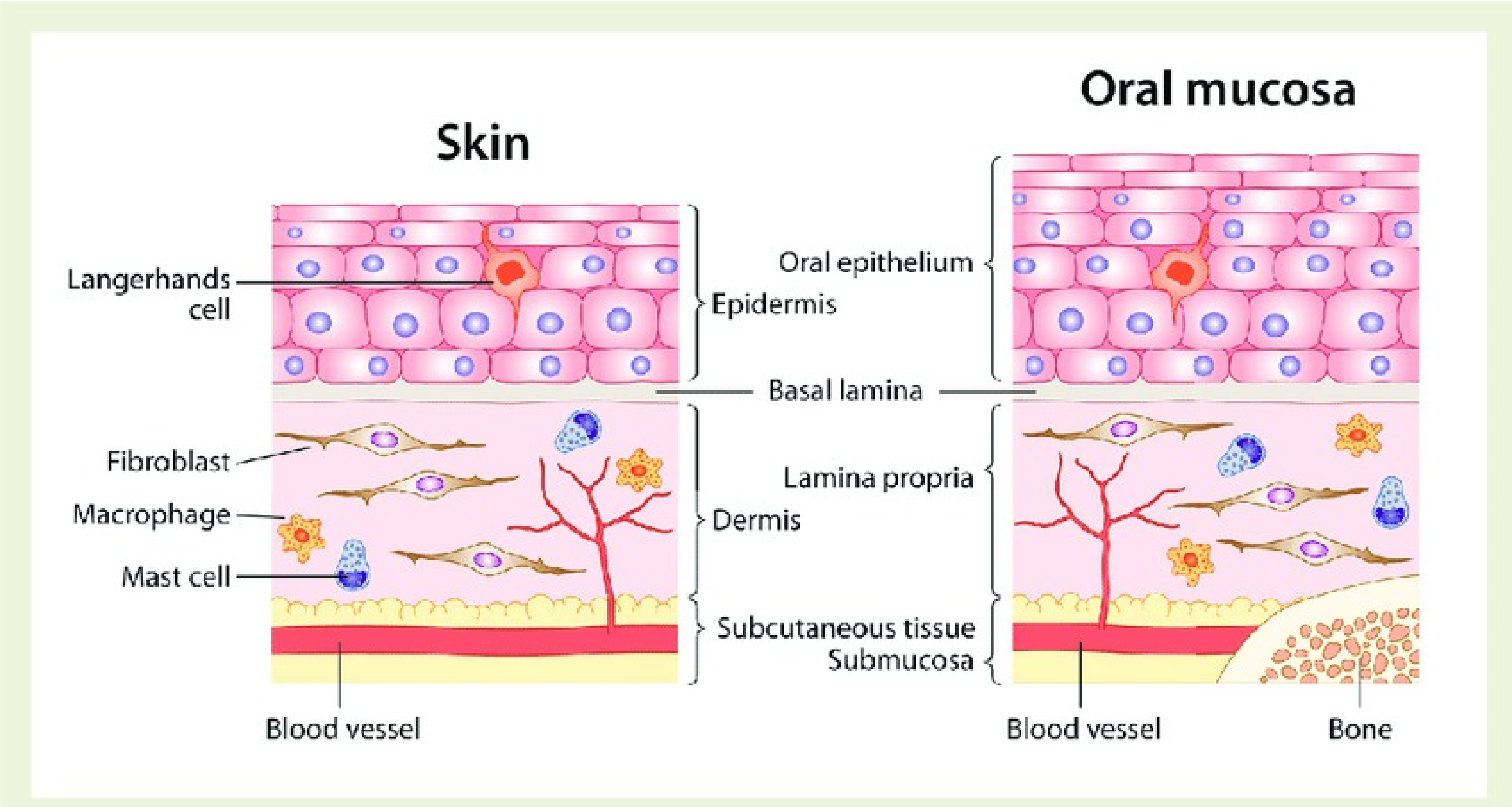
compaction - absorbing water and consolidating the indigestible residue into feces

regulation - coordinate reflexes within and between the intestine and other organs (including brain)

defecation - elimination of feces

General Anatomy

- Digestive tract is a tubular structure
- Digestive tract is open to the environment at both ends
- Material in lumen does not crossed the mucus membrane to enter the body tissues // The food residue never crosses the mucosa
- Nutrients in the GI lumen are outside of the body until they cross the mucosa of the absoptive cells and move into the body tissues


Skin
Oral mucosa
Langerhands cell
Fibroblast
Macrophage
Mast cell
Blood vessel
Epidermis
Oral epithelium
Basal lamina
Lamina propria
Dermis
Subcutaneous tissue
Submucosa
Blood vessel
Bone

Sphincter Muscles of the GI Track

- Smooth muscle regulate passage of food (i.e. bolus / chyme / fecal matter) through the digestive system
  - Fascicles arranged in circular pattern around tubular structure = sphincter muscles /// constrict to close movement through tubular structure
  - Sphincter muscles are smooth muscle with one exception - the "external anal sphincter" is a skeletal muscle
- List of sphincter muscles along alimentary canal
  - Upper esophageal sphincter (physiologic)
  - Lower esophageal sphincter (cardiac)
  - Pyloric sphincter
  - Ileocecal valve (not a true sphincter muscle)
  - Internal anal sphincter
  - External anal sphincter (skeletal muscle)

The Digestive System

- Most **nutrients** we eat cannot be used in their existing form
  - first food must be physically broken down into smaller "chucks", then......
  - macromolecules (polymers) broken down into smaller molecules (monomer).
  - digestion does not break apart molecules into individual atoms
- The digestive system is essentially a **"disassembly line" //** break down nutrients into a form that can be used by the body
  - nutrients must be *absorb across the mucosa*
  - *then distributed to the cells and tissues of the body*

Two Types of Digestion

- Mechanical digestion
  - the physical breakdown of food into smaller particles
  - cutting and grinding action of the teeth
  - churning action of stomach and small intestines
  - exposes more food surface to the action of digestive enzymes

Two Types of Digestion

- Chemical digestion

  a series of hydrolysis reactions (ie break covalent bonds) to turn dietary macromolecules into their monomers

  carried out by **digestive enzymes** produced by salivary glands, stomach, pancreas and small intestine

  results:

  polysaccharides into **monosaccharides**

  proteins into **amino acids**

  fats into **monoglycerides and fatty acids**

  nucleic acids into **nucleotides**

Note: Some nutrients are present in a usable form in ingested food /// absorbed without being digested - vitamins, free amino acids, minerals, cholesterol, and water

Pharynx

- Common term is throat
- A muscular funnel that connects oral cavity to esophagus and allows entrance of air from nasal cavity to larynx
- Where the digestive and respiratory tracts intersect
- Pharyngeal constrictors (*superior, middle, and inferior*) - circular muscles that force food downward during swallowing
  - when not swallowing, the inferior constrictor remains contracted to exclude air from the esophagus /// this constriction is considered to be the upper esophageal sphincter although it is not an anatomical feature
  - disappears at the time of death when the muscles relax, so it is a physiological sphincter, not an anatomical structure

Stomach

Mechanical digestion breaks up bolus, turns solid food into a liquid, and begins chemical digestion of protein and fat

The bolus is turned into chyme in the stomach – soupy or pasty mixture of semi-digested food in the stomach

In the stomach

Salivary amilase / deactivated by gastric acid

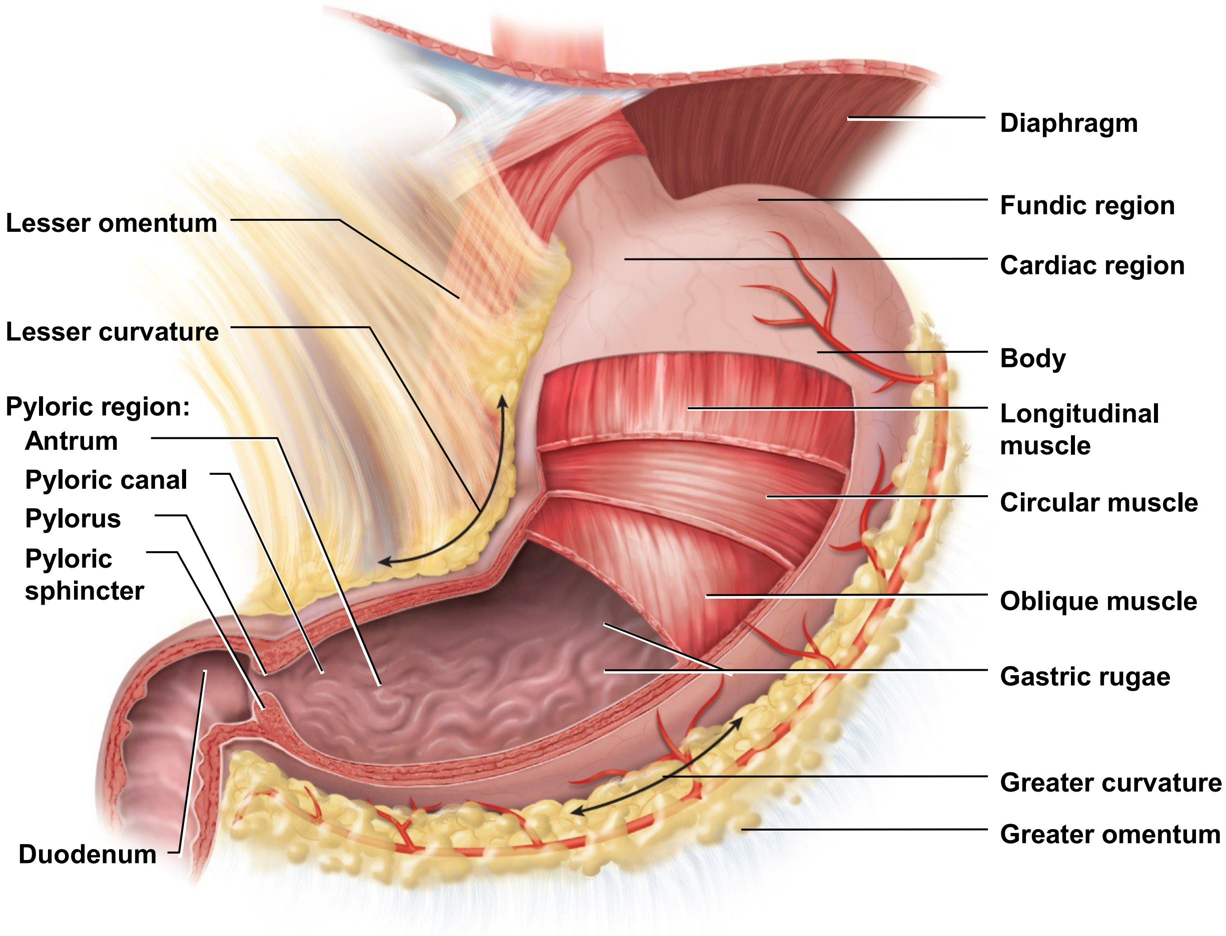
Lingual and gastric lipases / activated by gastric acid

Gastric HCl denatures protein

Gastric Pepsinogen converted by gastric HCl into active pepsin

Most chemical digestion occurs after the chyme passes into the small intestine (99%)

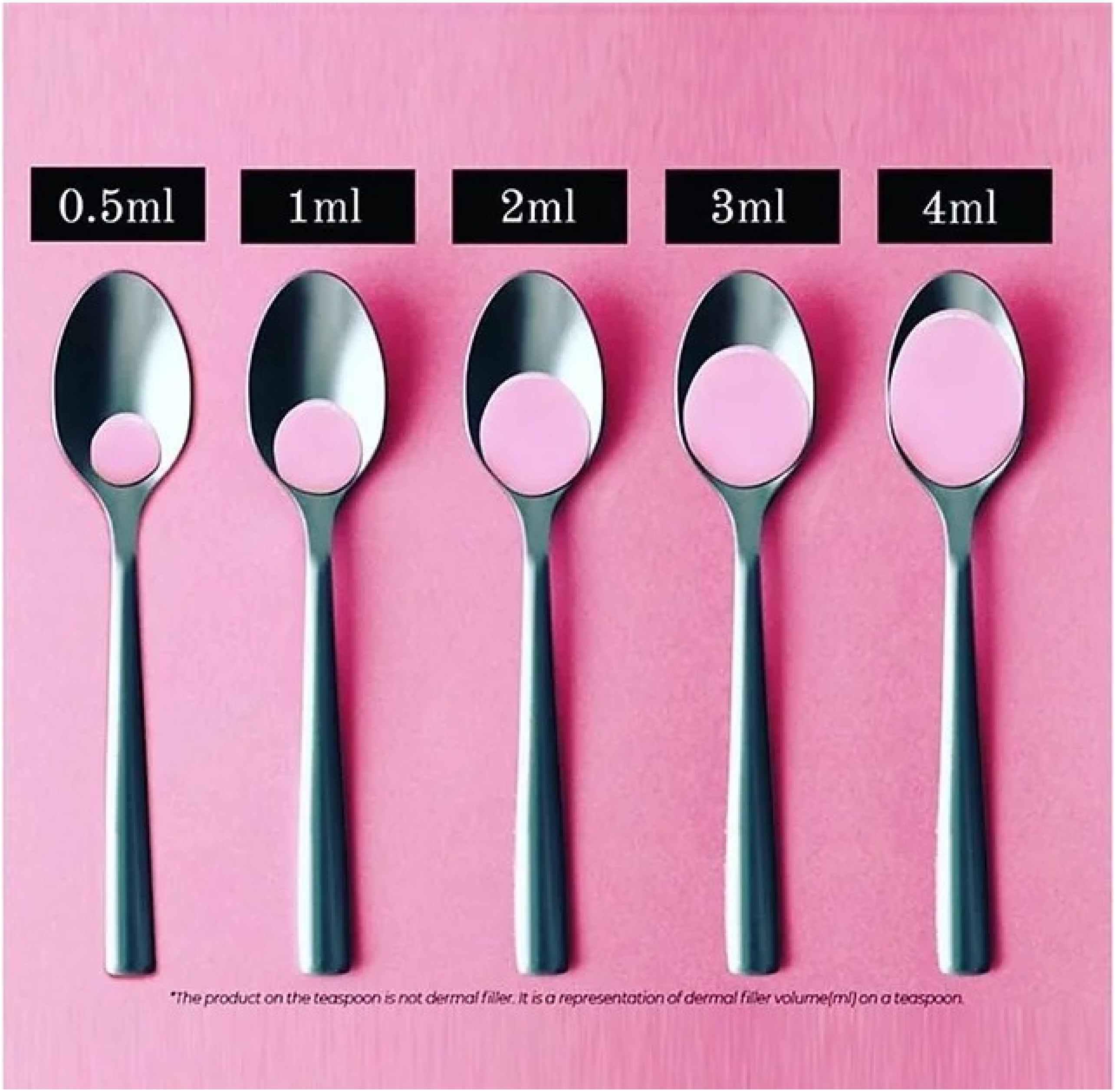
Stomach



bulge of fundus, narrowing of pyloric region, thickness of pyloric sphincter, and greater and lesser curvatures

Stomach

- Muscular sac in upper left abdominal cavity immediately inferior to the diaphragm
- Primary function is as a food storage organ and designed to release "small volumes" into duodenum
  - internal volume of about 50 mL when empty
  - 1.0 – 1.5 L after a typical meal
  - up to 4 L when extremely full and will extend nearly as far as the pelvis
  - takes approximately 4 hours to clear normal meal
  - antrum hold 30 ml
  - 3 ml of chyme released into duodenum per contraction



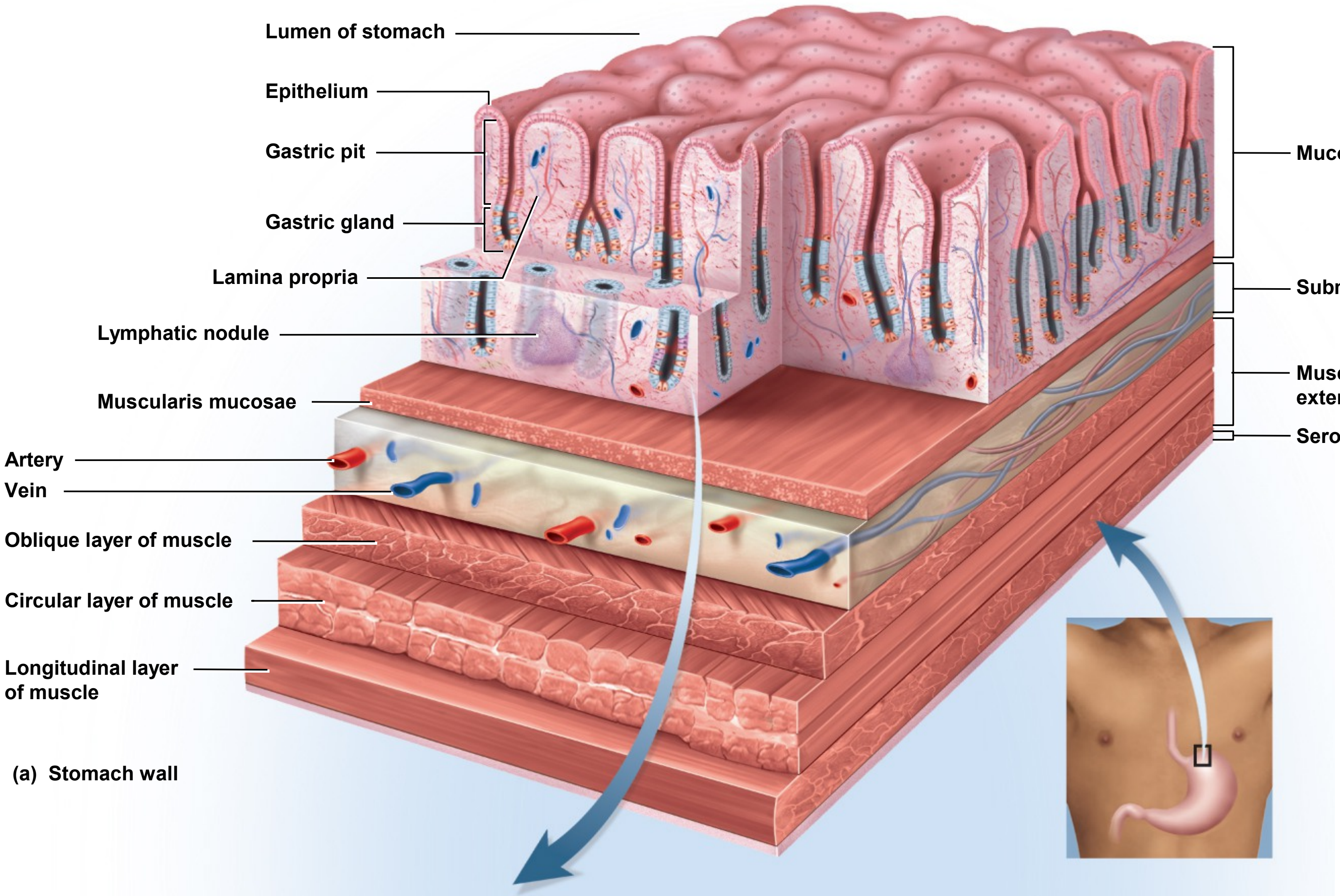
Teaspoon Volumes


50 ml
PYREX
No. 1000

1.5 Liters

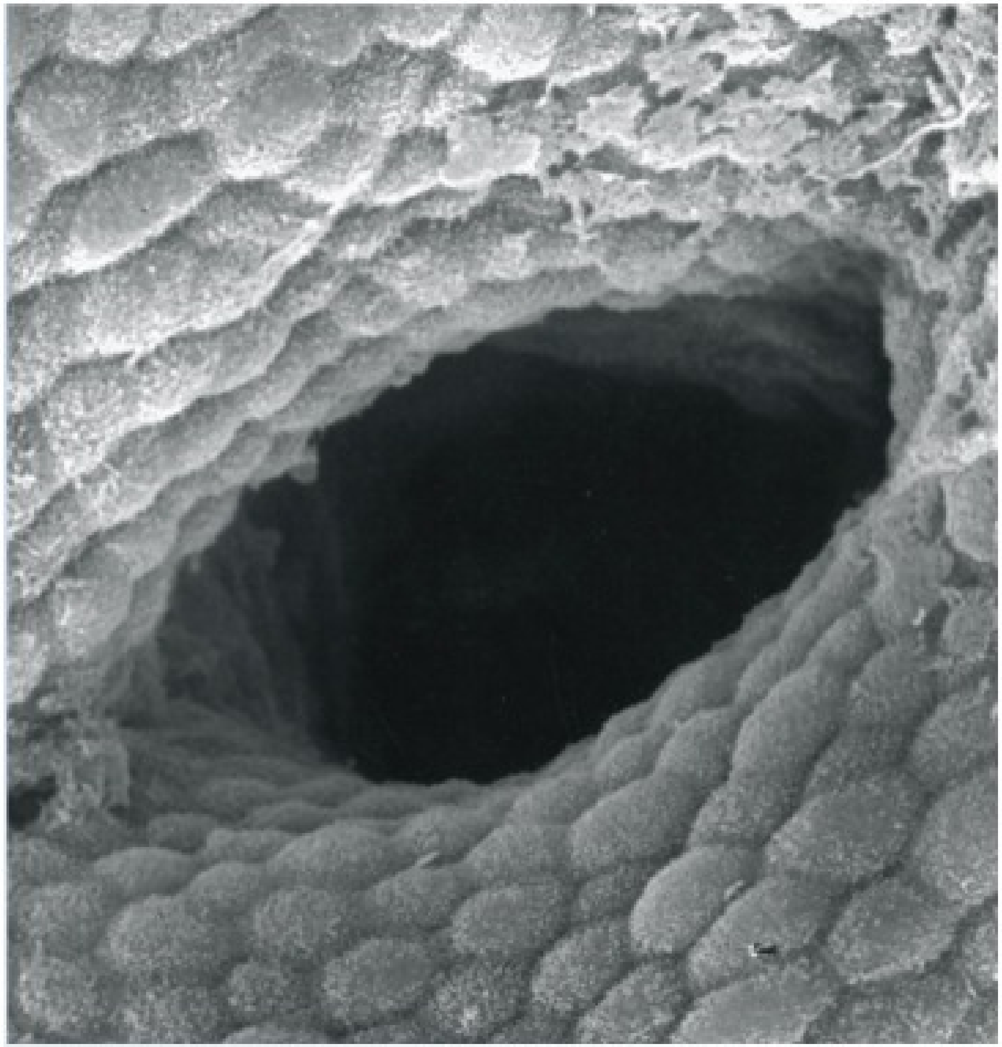

1 GALLON
4 QUARTS
8 PINTS
16 CUPS
128 OUNCES
3.8 LITERS
1 QUART
2 PINTS
4 CUPS
32 OUNCES
950 ML
1 PINT
2 CUPS
16 OUNCES
480 ML
1 CUP
16 TBSP
8 OUNCES
240 ML
1/2 CUP
8 TBSP
4 OUNCES
120 ML
1/4 CUP
4 TBSP
2 OUNCES
60 ML
1 OUNCE
2 TBSP
30 ML
1 TBLSP
3 TSP
1/2 OUNCE
15 ML
1 TSP
5 ML

Microscopic Anatomy



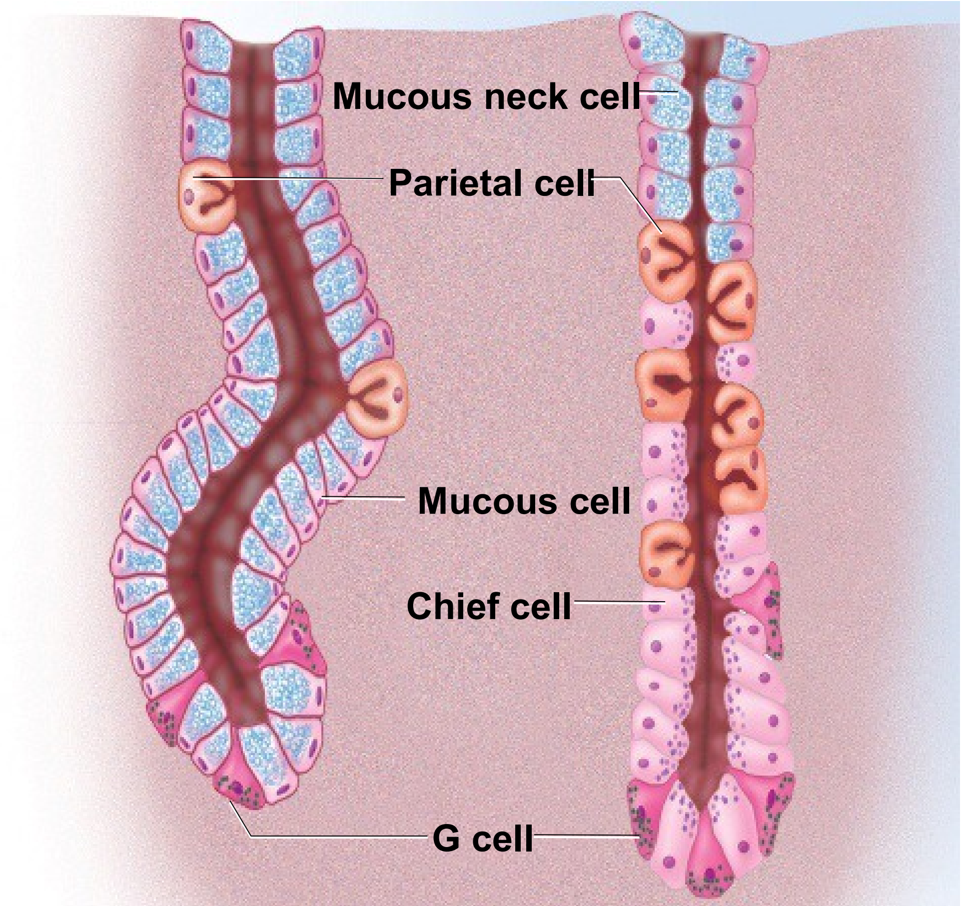
(a) Stomach wall

Opening of Gastric Pit



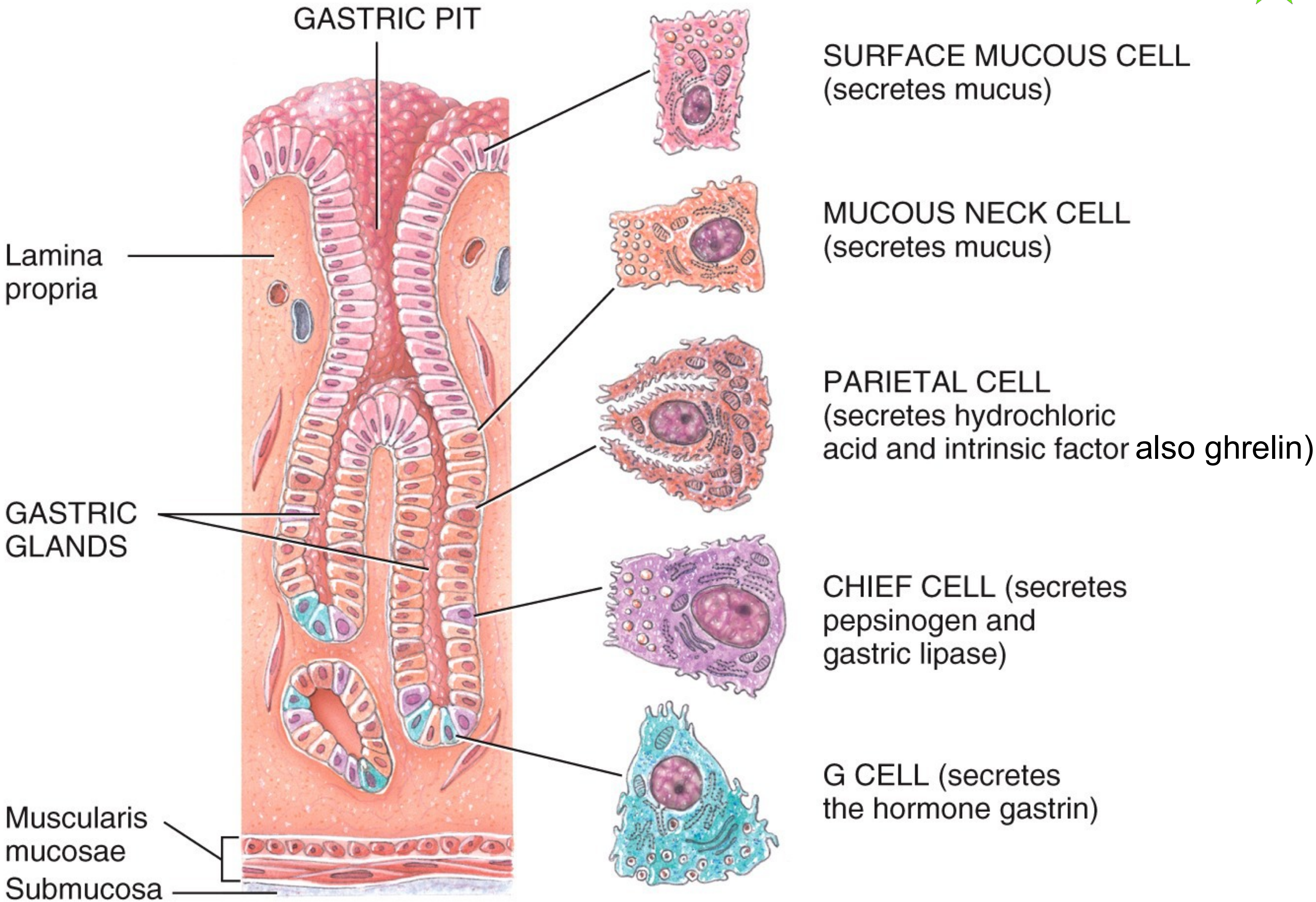
Visuals Unlimited

Pyloric and Gastric Glands



(b) Pyloric gland

(c) Gastric gland

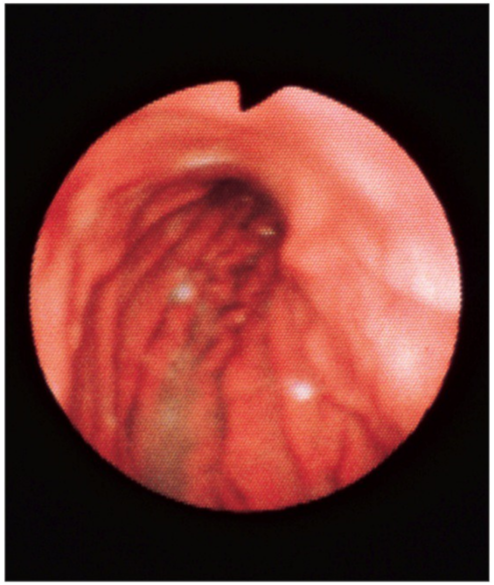


(b) Sectional view of the stomach mucosa showing gastric glands and cell types

How Does the Stomach Protect Itself From Digestion?

- Stomach is protected in three ways from the harsh acidic and enzymatic environment it creates
  - mucous coat – thick, highly alkaline mucus resists action of acid and enzymes
  - tight junctions - between epithelial cells prevent gastric juice from seeping between them and digesting the connective tissue of the lamina propria and beyond
  - epithelial cell replacement – stomach epithelial cells live only 3 to 6 days // sloughed off into the chyme and digested with the food // replaced rapidly by cell division in the gastric pits
- Breakdown of these protective measures can result in inflammation and peptic ulcer

Healthy Mucosa and Peptic Ulcer



(a) Normal

(b) Peptic ulcer

Gastritis, inflammation of the stomach, can lead to a **peptic ulcer** as pepsin and hydrochloric acid erode the stomach wall

Most ulcers are caused by acid-resistant bacteria, ***Helicobacter pylori*** that can be treated with antibiotics and Pepto-Bismol.

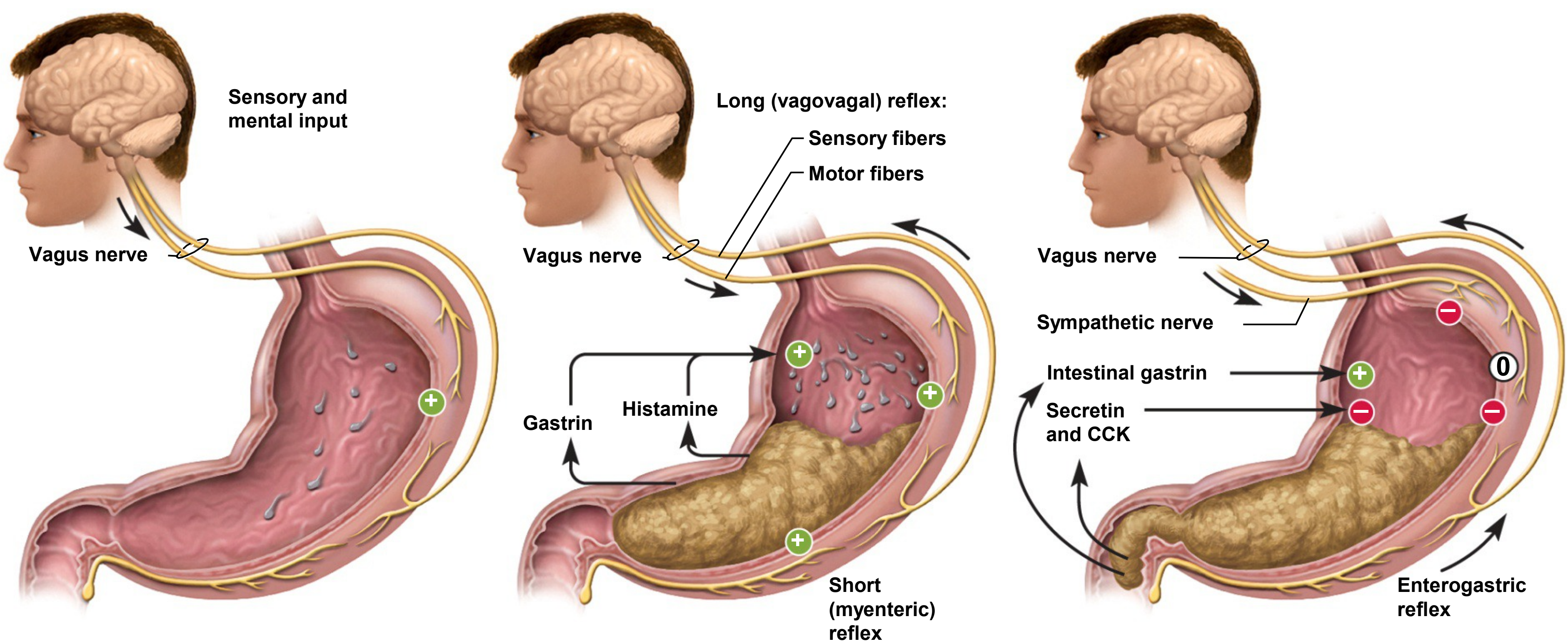
Gastric Motility

- Antrum holds about 30 ml of chyme
- As a parastaltic wave passes down the antrum, it moves about **3 mL of chyme** into the duodenum with each contraction
- Allows only a small amount of chyme into the duodenum /// enables the duodenum to
  - **neutralize the stomach acid**
  - **digest nutrients more efficiently**
- If duodenum is over filled then it inhibits gastric motility
- Typical meal emptied from stomach in **4 hours**
  - less time if the meal is more liquid
  - as long as 6 hours for a high fat meal

Stomach's Digestion and Absorption Functions

- Salivary and gastric enzymes partially digest protein and lesser amounts of starch and fat in the stomach
- Most chemical digestion and nearly all absorption occur after the chyme has passed into the small intestine
- Stomach does not absorb any significant amount of nutrients
- Stomach does absorb aspirin and some lipid-soluble drugs
- Alcohol is absorbed mainly by small intestine // intoxicating effects depends partly on how rapidly the stomach is emptied
- Note: stomach detoxifies about 20% of alcohol before it enters small intestine

Regulation of Gastric Function



1 Cephalic phase
Vagus nerve stimulates gastric secretion even before food is swallowed.

2 Gastric phase
Food stretches the stomach and activates myenteric and vagovagal reflexes. These reflexes stimulate gastric secretion. Histamine and gastrin also stimulate acid and enzyme

3 Intestinal phase
Intestinal gastrin briefly stimulates the stomach, but then secretin, CCK, and the enterogastric reflex inhibit gastric secretion and motility while the duodenum processes the chyme already in it. Sympathetic nerve fibers suppress gastric activity, while vagal (parasympathetic) stimulation of the stomach is now inhibited.

Key
- (+) Stimulation
- (−) Inhibition
- (0) Reduced or no effect

Regulation of Gastric Function – Cephalic Phase

- **First Phase = cephalic phase**
  - **stomach responds** to site, smell, taste, or thought of food
  - sensory and mental inputs converge on the **hypothalamus // relays signals to medulla oblongata**
  - **vagus nerve** fibers from medulla oblongata stimulate the **enteric nervous system** of stomach // this then stimulates gastric secretion

Regulation of Gastric Function – Gastric Phase

- **Second Phase = gastric phase**
  - period in which swallowed food and semi-digested protein in stomach activates gastric activity /// **two-thirds of gastric secretion** occurs in this phase
  - ***ingested food stimulates gastric activity in two ways***:
    - by **stretching the stomach**
      - activates **short reflex** mediated through **myenteric nerve plexus**
      - activates **long reflex** mediated through the **vagus nerves and the brainstem**
    - by **increasing the pH** of its contents

Regulation of Gastric Function – Gastric Phase

- **More on Second Phase**
  - **gastric secretion is stimulated by three chemicals**
    - **acetylcholine (ACh)** – secreted by parasympathetic nerve fibers
    - **histamine** – a paracrine secretion from enteroendocrine cells in the gastric glands
    - **gastrin** – a hormone produced by the enteroendocrine cells (i.e. **G cells**) in pyloric glands

Regulation of Gastric Function – Intestinal Phase

- **Third Phase = intestinal phase**
  - stage in which the duodenum responds to arriving chyme and moderates gastric activity through hormones and nervous reflexes
  - duodenum **initially enhances** gastric secretion, but then **inhibits gastric secretions**
    - stretching of the duodenum accentuates vagovagal reflex that stimulates the stomach
    - peptides and amino acids in chyme stimulate **G cells** of the duodenum to secrete more **gastrin** which further stimulates the stomach
    - Then inhibits gastric secretion by the enterogastric reflex // see next slide

Regulation of Gastric Function - Intestinal Phase

- **The Enterogastric Reflex**
  - duodenum sends **inhibitory signals** to the stomach by way of the enteric nervous system
  - pyloric sphincter contracts tightly to limit chyme entering duodenum // gives duodenum time to process chyme
  - enteroendocrine cells also participate in this reflex (see next slide)
  - at same time signals also sent to the medulla oblongata - triggered by acid and semi-digested fats in the duodenum
    - » **inhibits vagal nuclei** – reducing vagal stimulation of the stomach
    - » **stimulate sympathetic neurons** – send inhibitory signals to the stomach

Regulation of Gastric Function – Enterogastric Reflex

Chyme also stimulates duodenal enteroendocrine cells to release these hormones:

- Secretin
- Cholecystokinin
- Glucose dependent insulinotropic peptide (gastric inhibiting peptide)

Secretin and cholecystokinin stimulate secretions from the pancreas and gall bladder

During intestinal phase secretin and cholecystokinin inhibit gastric secretions

GDI inhibit gastric secretions but stimulate insulin secretion by pancreas in preparation for processing nutrients about into small intestine

Microscopic Anatomy

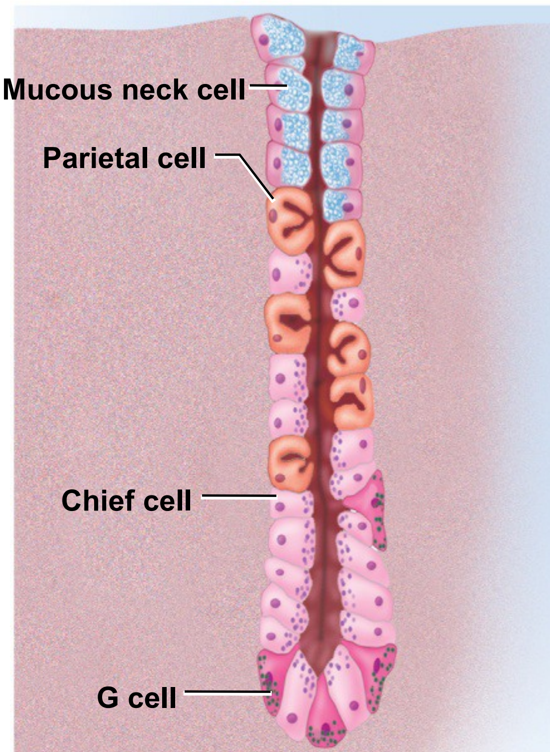
- **simple columnar epithelium** covers mucosa
  - apical regions of its surface cells are filled with **mucin**
  - swells with water and becomes **mucus** after it is secreted
- mucosa and submucosa flat when stomach is full, but form longitudinal wrinkles called **gastric rugae** when empty
- **muscularis externa** has three layers instead of two /// outer longitudinal, middle circular and inner oblique layers
- **gastric pits** – depressions in gastric mucosa
  - lined with simple columnar epithelium
  - two or three tubular glands open into the bottom of each gastric pit
    - **cardiac glands** in cardiac region
    - **pyloric glands** in pyloric regions
    - **gastric glands** in the rest of the stomach

Cells of Gastric Glands

- **<u>Regenerative (stem) cells</u>** – found in the base of the pit and in the neck of the gland
  - divide rapidly and produce a continual supply of new cells to replace cells that die
- **<u>Mucous cells</u> – secrete mucus**

  predominate in cardiac and pyloric glands

  in gastric glands, called **mucous neck cells** since they are concentrated at the neck of the gland
- **<u>Parietal cells</u>** – found mostly in the upper half of the gland // produce these secretions
  - hydrochloric acid (HCl)
  - intrinsic factor
  - ghrelin / hunger hormone / stomach empty sends signal to hypothalamus – go find food!

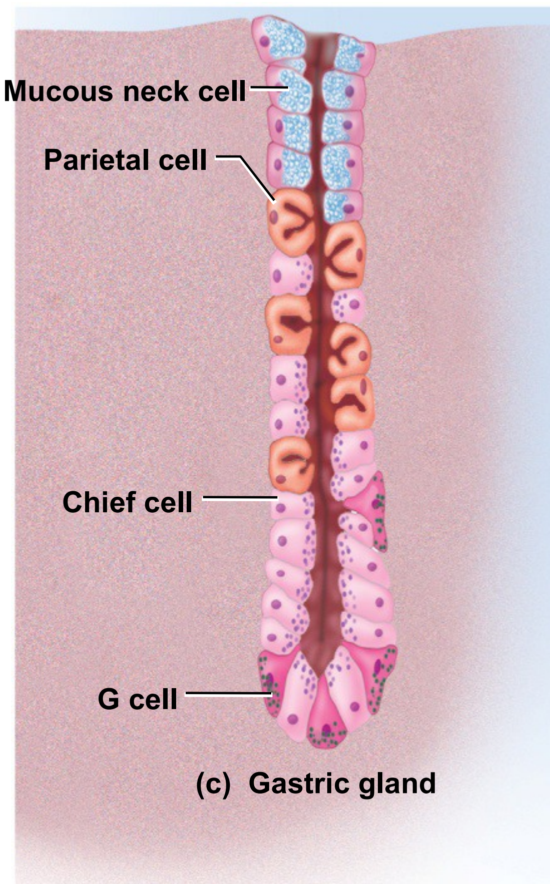


(c) Gastric gland

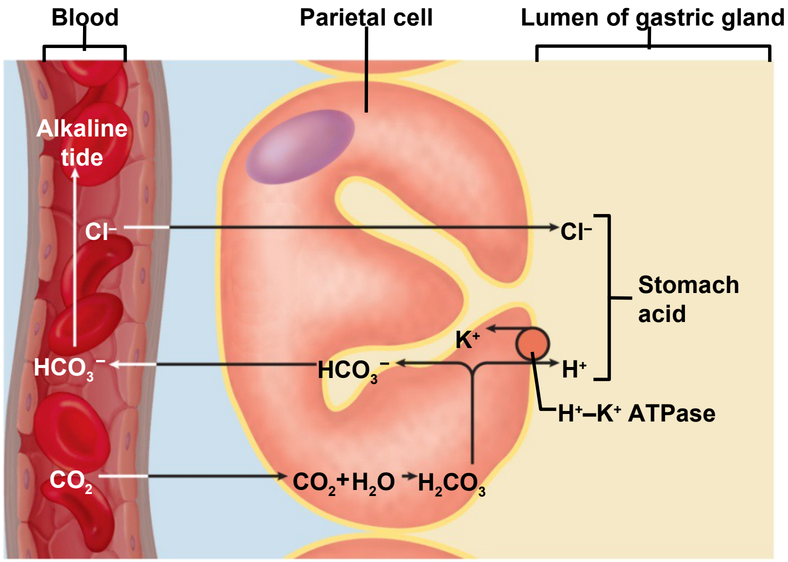
Cells of Gastric Glands

- **Chief cells** – most numerous
  - secrete **gastric lipase** and **pepsinogen**
  - dominate lower half of gastric glands
  - absent in pyloric and cardiac glands

- **What are the enteroendocrine cells of the gastric pit?**
  - concentrated in lower end of gland
  - consist of up to eight different cell lines (e.g. G cell = gastrin)
  - secrete **hormones** and **paracrine messengers** that regulate digestion

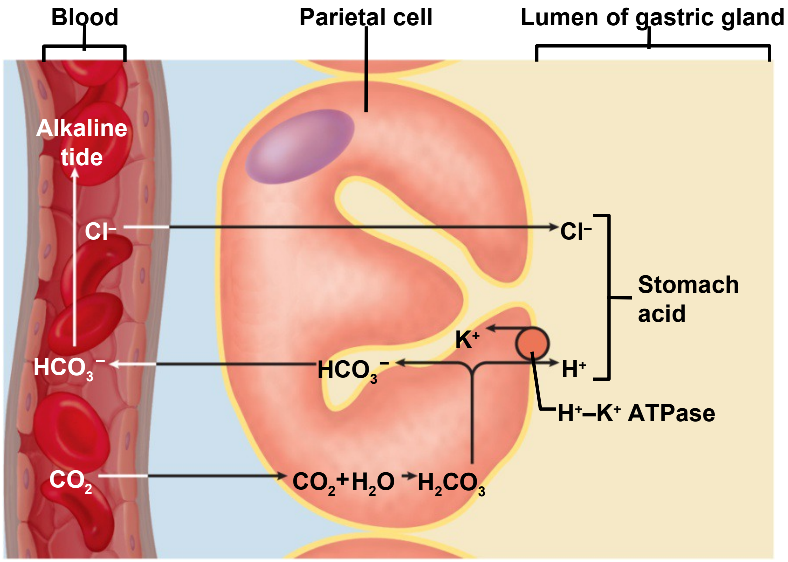


(c) Gastric gland



Hydrochloric Acid

- **Gastric juice** has a high concentration **of hydrochloric acid** /// pH as low as 0.8
- **Parietal cells produce HCl** (use carbonic anhydrase (CAH) to make Hcl)
-
- What is an acid? How do we make free protons?
- See Next Slide



Hydrochloric Acid

- $CO_2 + H_2O \xrightarrow{\text{Carbonic Anhydrase}} H_2CO_3 \rightarrow HCO_3^- + H^+$

- **H^+** is pumped into gastric gland's lumen by the antiport, **H^+- K^+ ATPase** pump /// antiporter uses ATP to pump H^+ out and K^+ in

- **HCO_3^-** exchanged for **Cl^- (chloride shift)** from blood plasma
  - **Cl^-** (chloride ion) pumped into the lumen of gastric gland to join H^+ forming **HCl**
  - elevated HCO_3^- (bicarbonate ion) in blood causes **alkaline tide** increasing blood pH

Functions of Hydrochloric Acid

- Activates **pepsin** and **lingual lipase**
- Breaks up connective tissues and plant cell walls // helps liquefy food to form **chyme**
- Converts ingested **ferric ions (Fe^{3+})** to **ferrous ions (Fe^{2+})** // Fe^{2+} absorbed and used for hemoglobin synthesis
- Contributes to nonspecific disease resistance by destroying most ingested pathogens

Pepsin

- Zymogens are digestive enzymes secreted as inactive proteins /// converted to active enzymes by removing some of their amino acids

- Pepsinogen is a zymogen secreted by the chief cells /// *HCl converts pepsinogen into pepsin after enzyme is inside stomach*

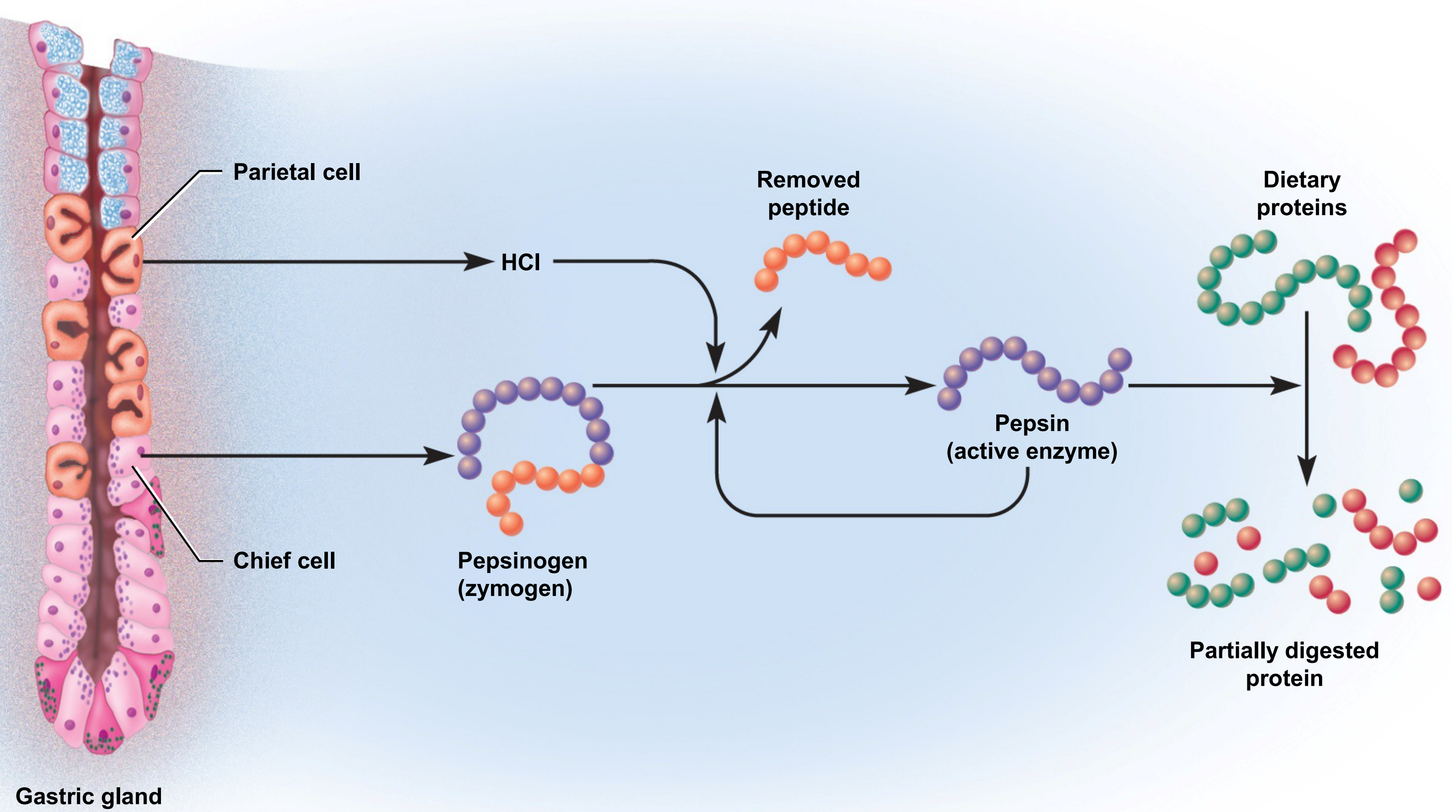
  - hydrochloric acid removes some of its amino acids and forms pepsin that digests proteins

  - autocatalytic effect – as some pepsin is formed, it converts more pepsinogen into more pepsin // positive feedback mechanism

- Pepsin digests dietary proteins into shorter peptide chains

  - Note: protein digestion starts in stomach and is completed in the small intestine

Production and Action of Pepsin



Gastric Lipase

- Produced by **chief cells**
- Important for infants (not produced in adults)
- **Gastric lipase** and **lingual lipase** play a minor role in digesting dietary fats
  - digests 15% of dietary fats in the stomach
  - pancreatic lipase accounts for 85% of fats digested in the small intestine

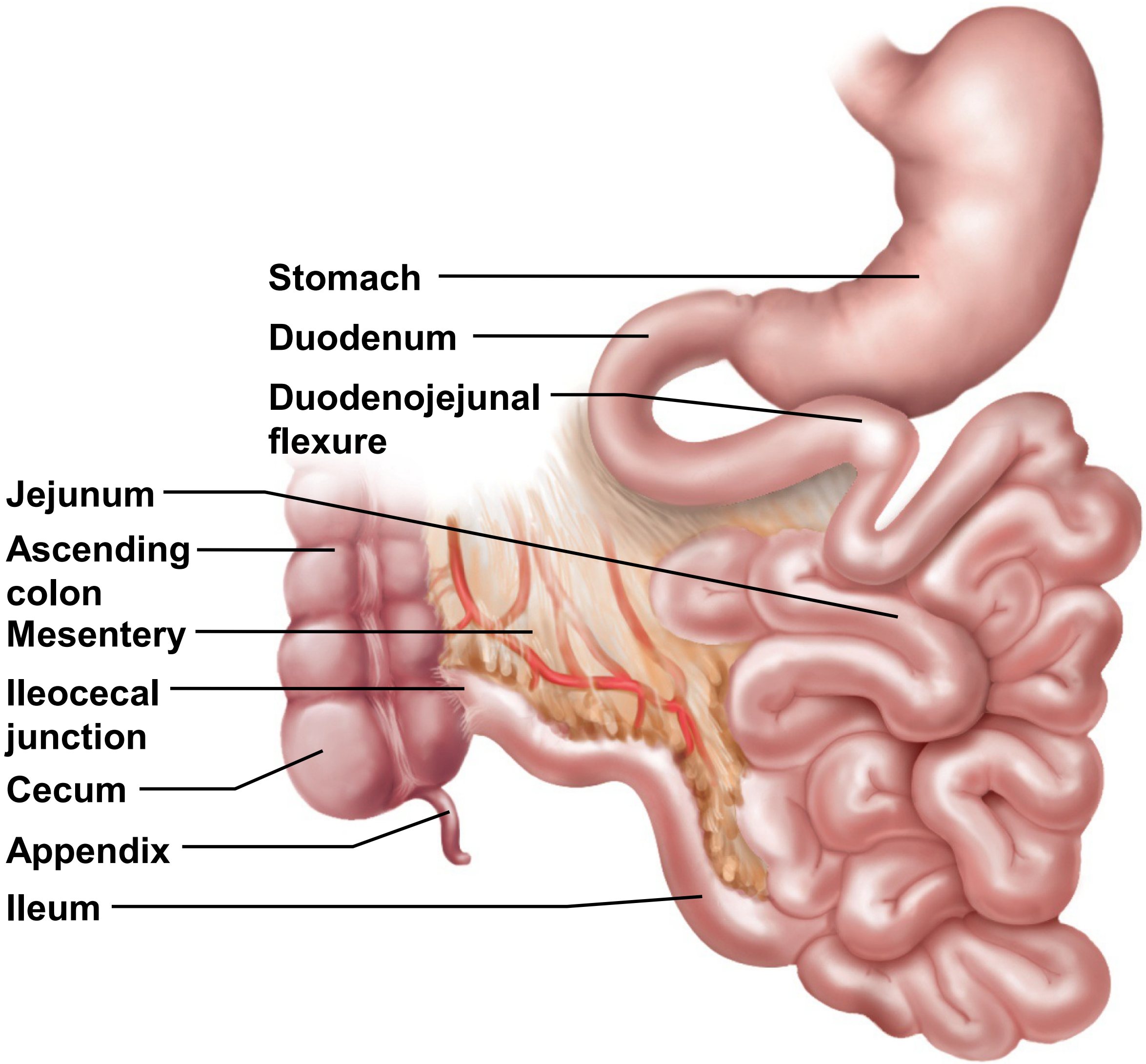
Intrinsic Factor

- A glycoprotein secreted by parietal cells
- Intrinsic factor is essential for the absorption of vitamin B_{12} by the small intestine
  - binds vitamin B_{12} and intestinal cells absorb this complex by receptor-mediated endocytosis
- Vitamin B_{12} is needed to synthesize hemoglobin // required to prevents pernicious anemia
- Secretion of intrinsic factor is the only indispensable function of the stomach
- Digestion continues if stomach is removed (gastrectomy), but B_{12} supplements will be needed

Small Intestine

- Nearly all chemical digestion and nutrient absorption occurs in small intestine (99%)
- The longest segment of the digestive tract
  - 2.7 to 4.5 m long in a living person
  - 4 to 8 m long in a cadaver where there is no muscle tone
- Small refers to the diameter not its length // diameter = 2.5 cm (1 inch)

Small Intestine



Coiled mass filling most of the abdominal cavity inferior to the stomach and the liver

Duodenum

Duodenum

the first 25 cm (10 inches)

begins at the **pyloric valve**

major and minor duodenal papilla distal to pyloric valve // receives **major and minor pancreatic ducts** respectively

arches around the **head of the pancreas**

ends at a sharp bend called the **duodenojejunal flexure**

most is **retroperitoneal**

Secretions into the Duodenum

- **Duodenal glands** – in submucosa of duodenum
  - secrete an abundance of **bicarbonate-rich mucus**
  - neutralizes stomach acid and shields the mucosa from its erosive effects
- Note: large population of **defensive lymphocytes** throughout lamina propria and submucosa of small intestine

Jejunum

- Jejunum
  - first 40% of small intestine beyond duodenum
  - roughly 1.0 to 1.7 m in a living person
  - has large, tall, closely spaced circular folds
  - its wall is relatively thick and muscular
  - especially rich blood supply which gives it a red color
  - most digestion and nutrient absorption occurs here
  - jejunum means empty

Ileum

forms the last 60% of the post duodenal small intestine

about 1.6 to 2.7 m

thinner, less muscular, less vascular, and paler pink color

Peyer patches – prominent lymphatic nodules in clusters on the side opposite the mesenteric attachment

- readily visible with the naked eye
- become progressively larger approaching the large intestine

Illium - Distal End of Small Intestine

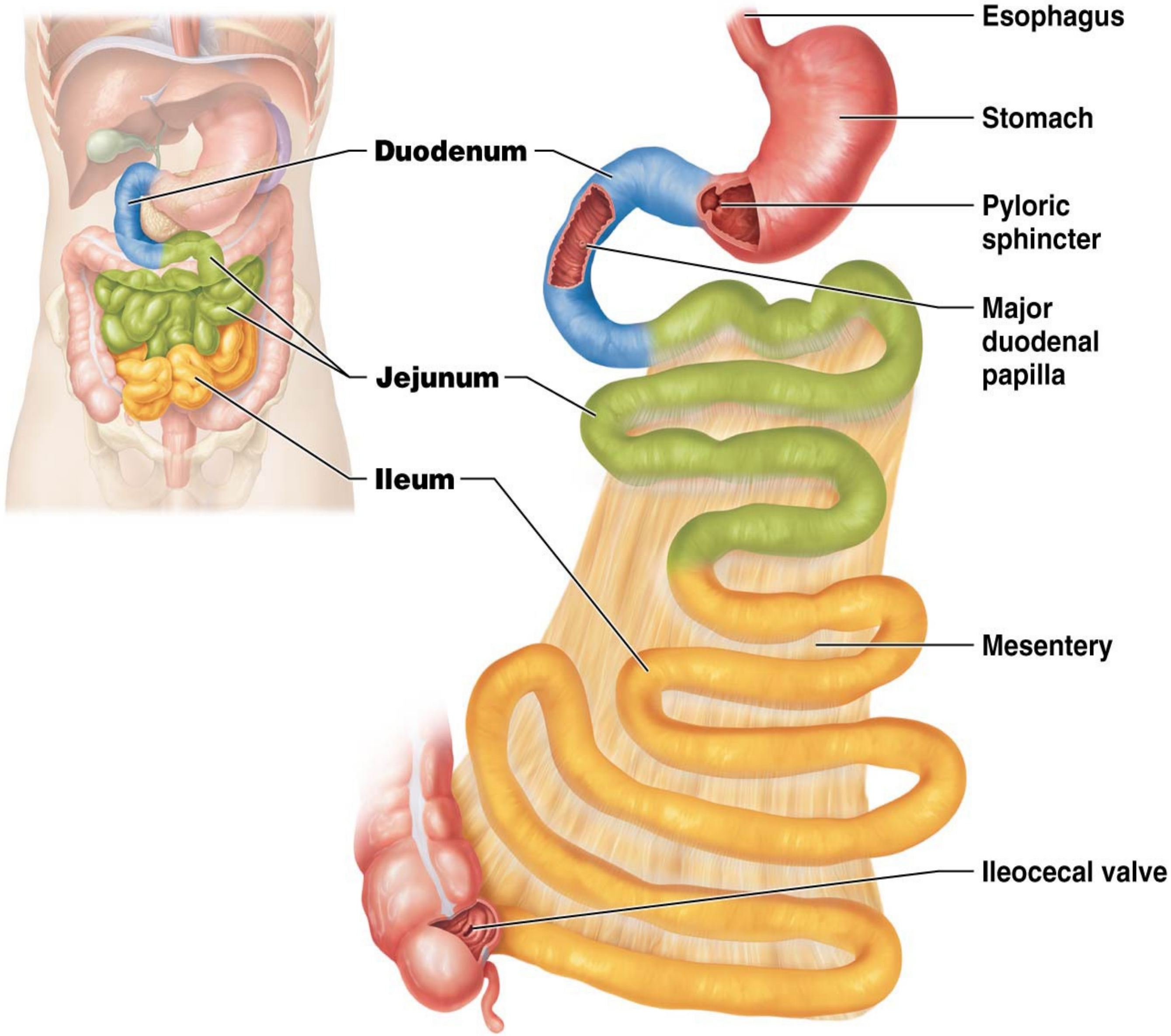
ileocecal junction - the end of the small intestine where the **ileum** joins the **cecum** of the large intestine

ileocecal valve - a sphincter formed by the thickened muscularis of the ileum

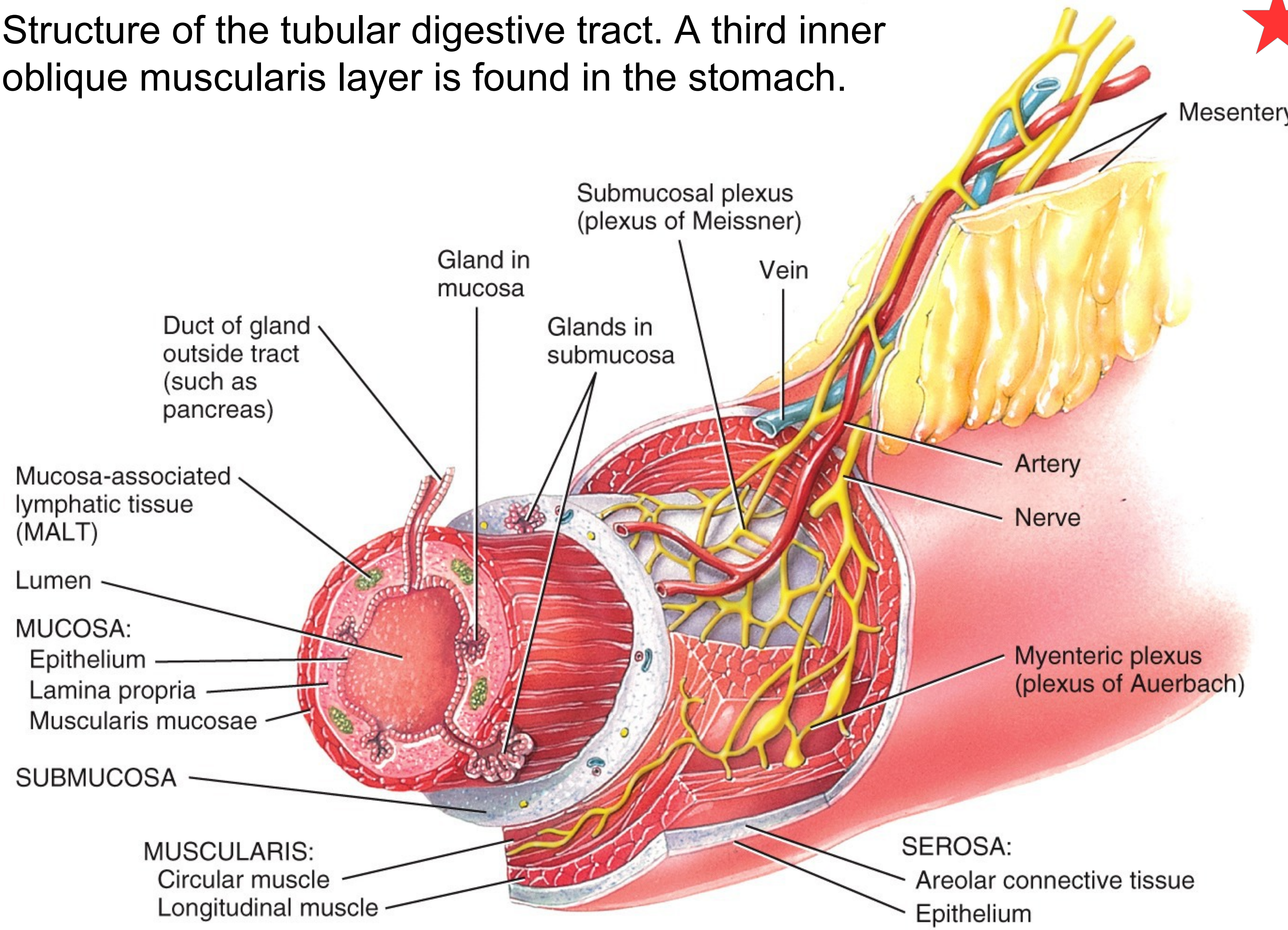
protrudes into the cecum // regulates passage of food residue into the larg intestine

both jejunum and ileum are **intraperitoneal** and covered with **serosa**

Small Intestine



Structure of the tubular digestive tract. A third inner oblique muscularis layer is found in the stomach.



Intestinal Motility

- Contractions of small intestine serve three functions:
  - to mix chyme with intestinal juice, bile, and pancreatic juice
    - to neutralize acid
    - digest nutrients more effectively
  - to bring chyme in contact with the mucosa for contact digestion and nutrient absorption
  - to move residue toward large intestine

Motility and **Secretion C**ontrolled By

Neural control

short (myenteric) reflexes – stretch or chemical stimulation acts through myenteric plexus /// stimulates parastaltic contractions of swallowing

long (vagovagal) reflexes - parasympathetic stimulation of digestive motility and secretion

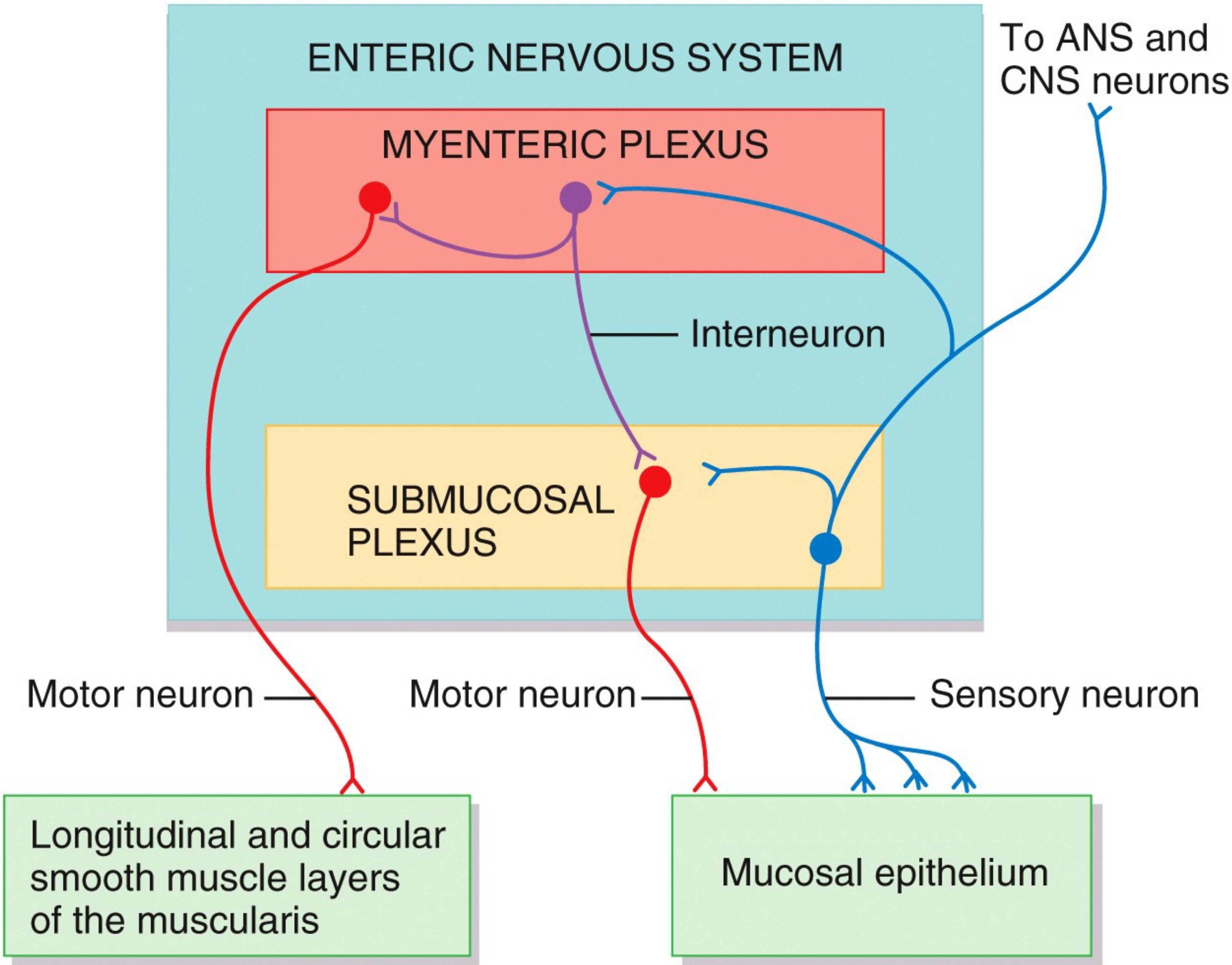
Hormones

chemical messengers secreted into bloodstream, and stimulate distant parts of the digestive tract

enteroendocrines: Gastrin, secretin, and cholecystokinin (CCK),

Paracrine secretions

chemical messengers that diffuse through the tissue fluids to stimulate nearby target cells


ENTERIC NERVOUS SYSTEM
To ANS and CNS neurons
MYENTERIC PLEXUS
Interneuron
SUBMUCOSAL PLEXUS
Motor neuron
Motor neuron
Sensory neuron
Longitudinal and circular smooth muscle layers of the muscularis
Mucosal epithelium

Intestinal Motility
Segmentation VS Peristalsis

Segmentation – the movement in which stationary ringlike constrictions appear in several places along the intestine // this is designed not to advance chyme but to mix chyme with pancreatic enzymes and bring nutrients into contact with brush boarder enzymes

they relax and new constrictions form elsewhere
most common kind of intestinal contraction
pacemaker cells in muscularis externa set rhythm of Segmentation

contractions about 12 times per minute in the duodenum // 8 to 9 times per minute in the ileum

a fter most nutrients have been absorbed and little remains but undigested residue, segmentation declines and peristalsis begins

Peristalsis
Also Called the Migrating Motor Complex

- Causes gradual movement of contents towards colon

- **Peristaltic wave** begins in the duodenum, travels 10 to 70 cm and dies out /// followed by another wave starting further down the tract

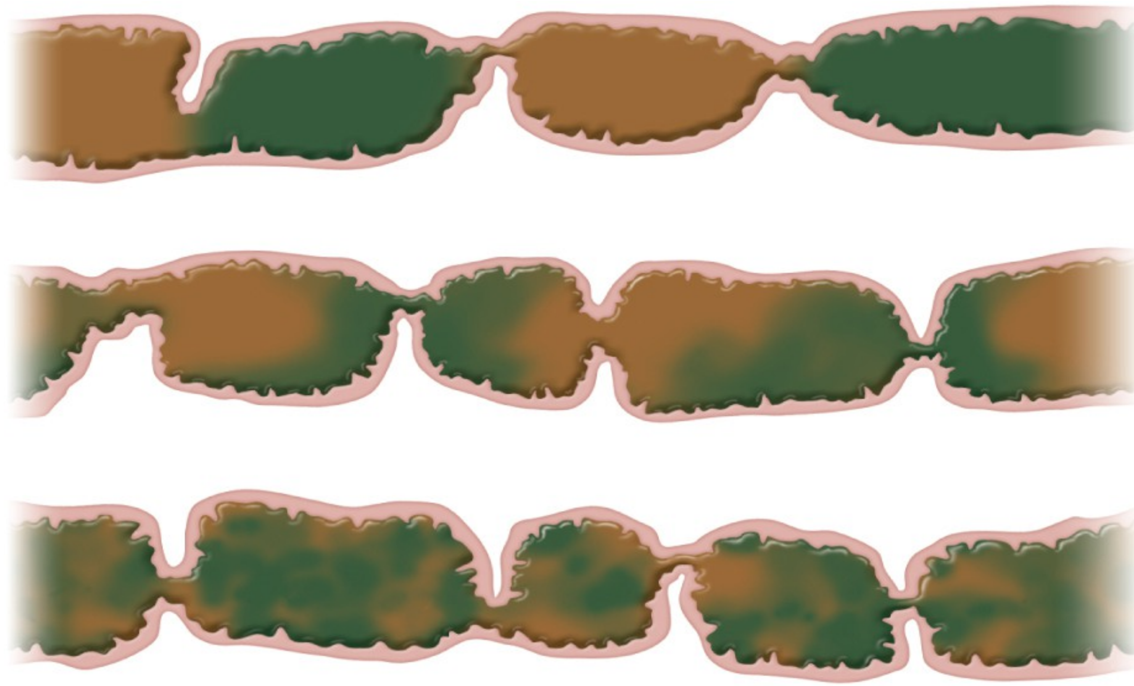
- **Migrating motor complex** – successive, overlapping waves of contraction /// milk chyme toward colon over a period of two hours

- **The ileocecal valve** usually closed

  – food in stomach triggers **gastroileal reflex** that enhances segmentation in the ileum and relaxes the valve

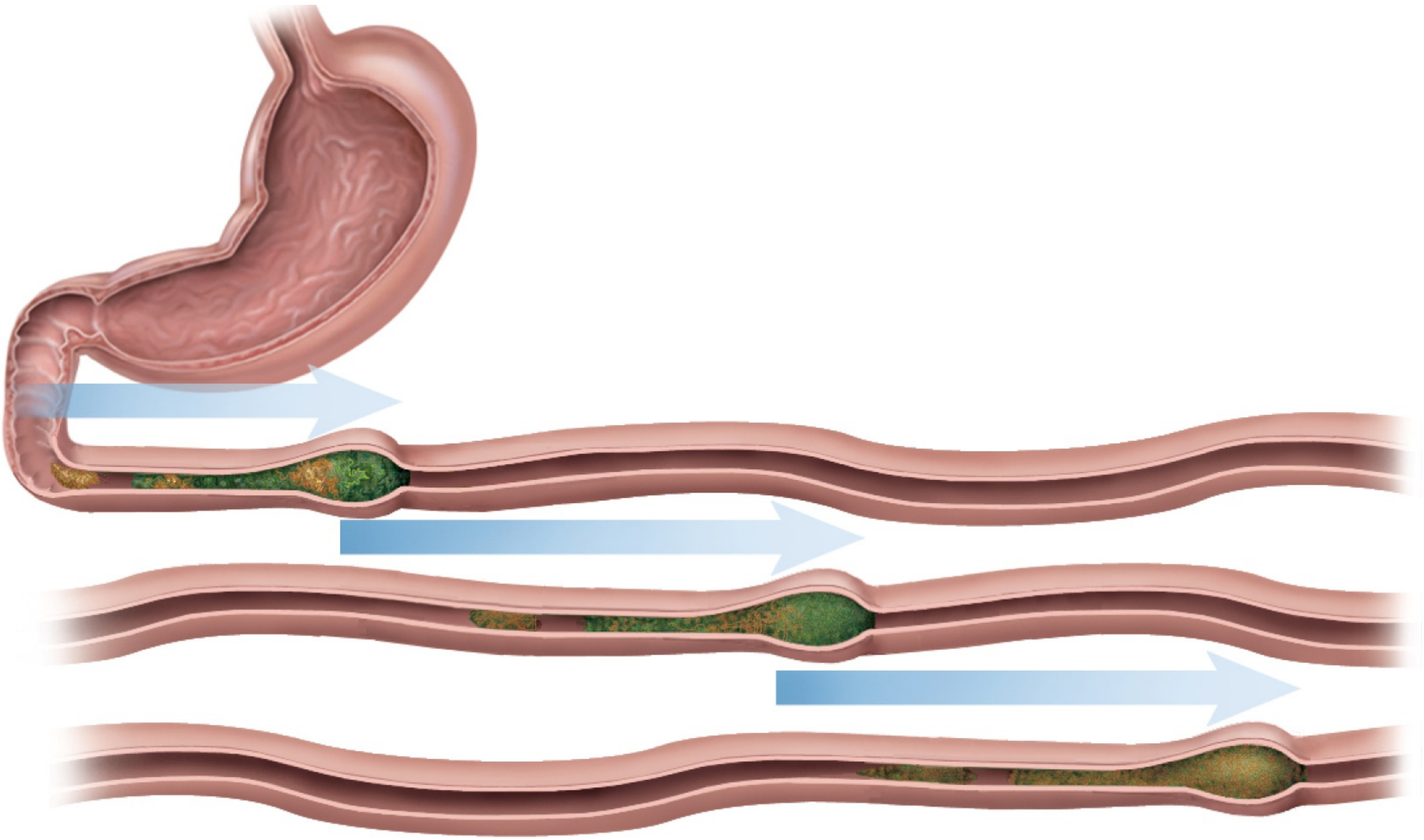
  – as **cecum** fills with residue, pressure pinches the valve shut /// prevents reflux of cecal contents into the ileum

Segmentation in Small Intestine



(a) Segmentation

purpose of segmentation is to mix and churn not to move material along as in peristalsis



(b) Peristalsis: purpose to advance chyme towards large intestine

How is the surface area in small intestine increased?

Need large internal surface area for effective digestion and absorption

Tissue layers have **modifications for nutrient digestion and absorption //** lumen lined with **simple columnar epithelium**

greater length and **<u>three types of internal folds</u>** or projections

circular folds **(plicae circulares) –** increase surface area by a factor of 2 to 3

villi – increase surface area by a factor of 10

microvilli – increase the surface area by a factor of 20 // 1,700 per cell

How is the surface area in small intestine increased?

- **Circular folds** (plicae circulares)
  - largest folds of intestinal wall // up to 10 mm high
  - involve only mucosa and submucosa
  - occur from the duodenum to the middle of the ileum
  - cause chyme flow in spiral path causing more contact with mucosa
  - promotes more thorough mixing and nutrient absorption
  - relatively small and sparse in ileum and not found in distal half // most nutrient absorption is completed by this point

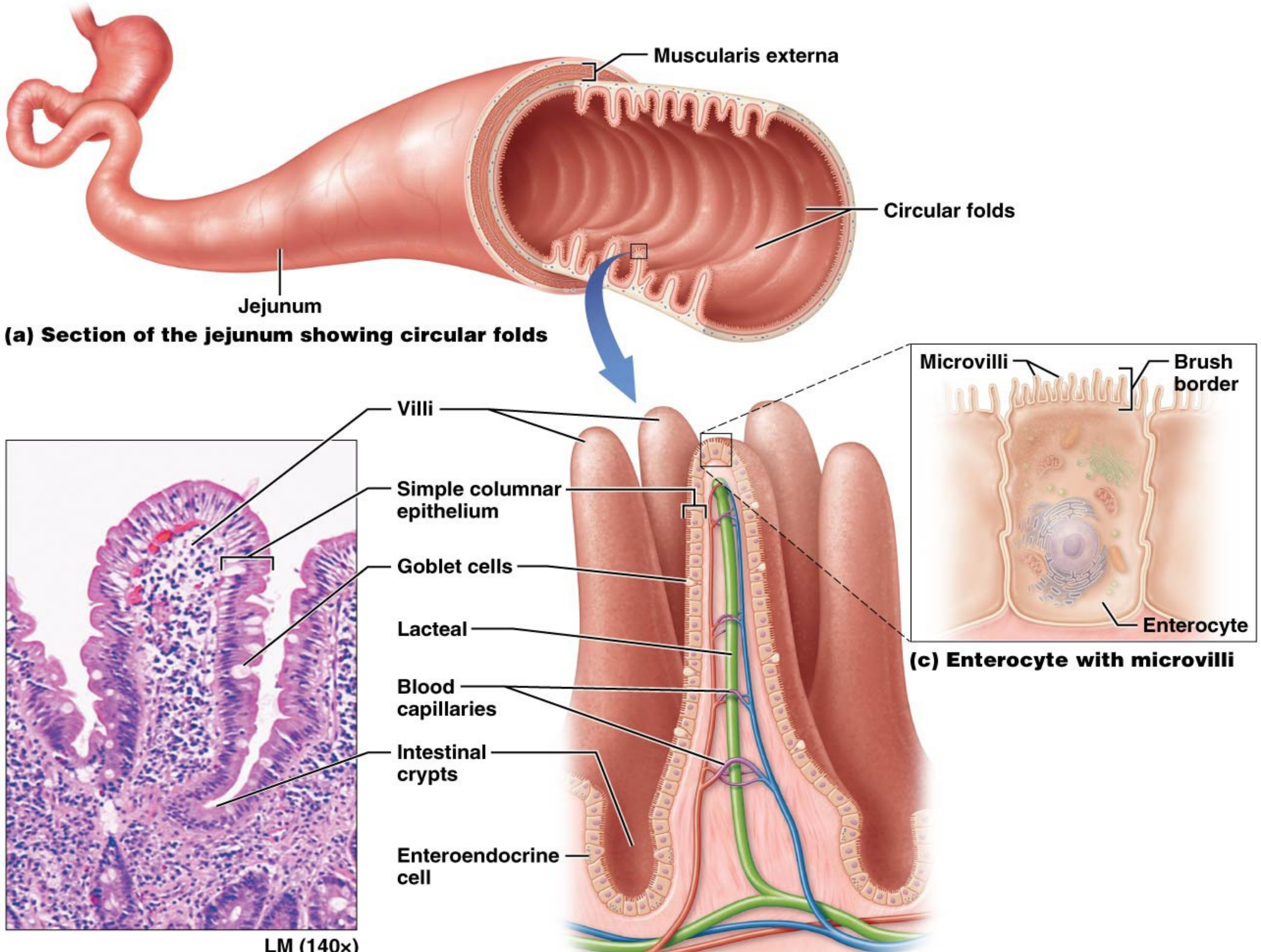
How is the surface area in small intestine increased?

- **Villi**
  - fingerlike projections 0.5 to 1 mm tall // make mucosa look fuzzy
  - villus covered with two types of epithelial cells
    - **absorptive cells (enterocytes)**
    - **goblet cells** – secrete mucus
  - epithelia joined by tight junctions that prevent digestive enzymes from seeping between them

How is the surface area in small intestine increased?

- **Villi**
  - core of villus filled with areolar tissue of the lamina propria
    - embedded in this tissue are an arteriole, a capillary network, a venule, and a lymphatic capillary called a **lacteal**
    - blood capillaries of villus absorb most of the nutrients
    - lacteal absorbs most lipids

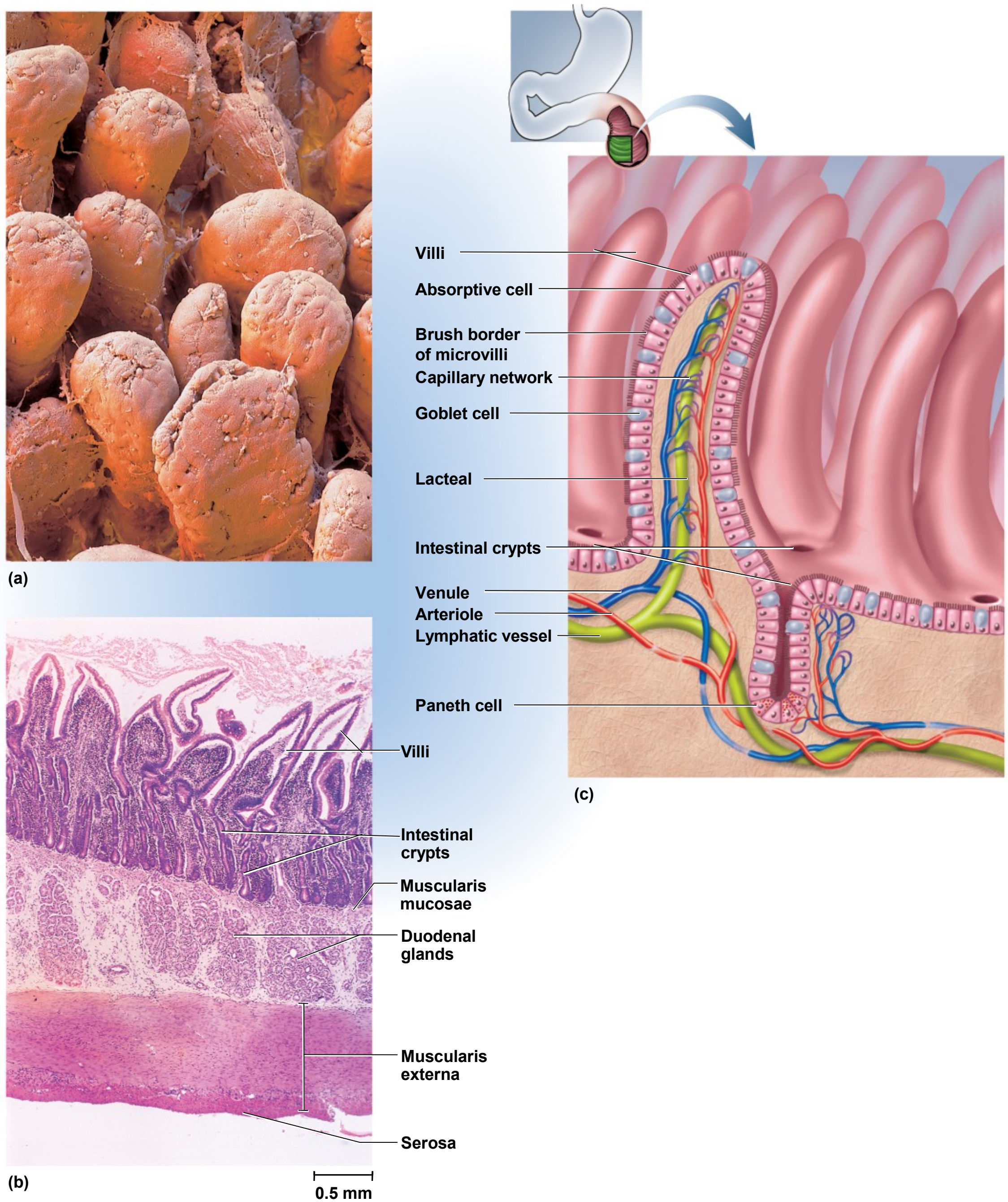
Why is it important to increase the surface area in the small intestines?



(a) Section of the jejunum showing circular folds

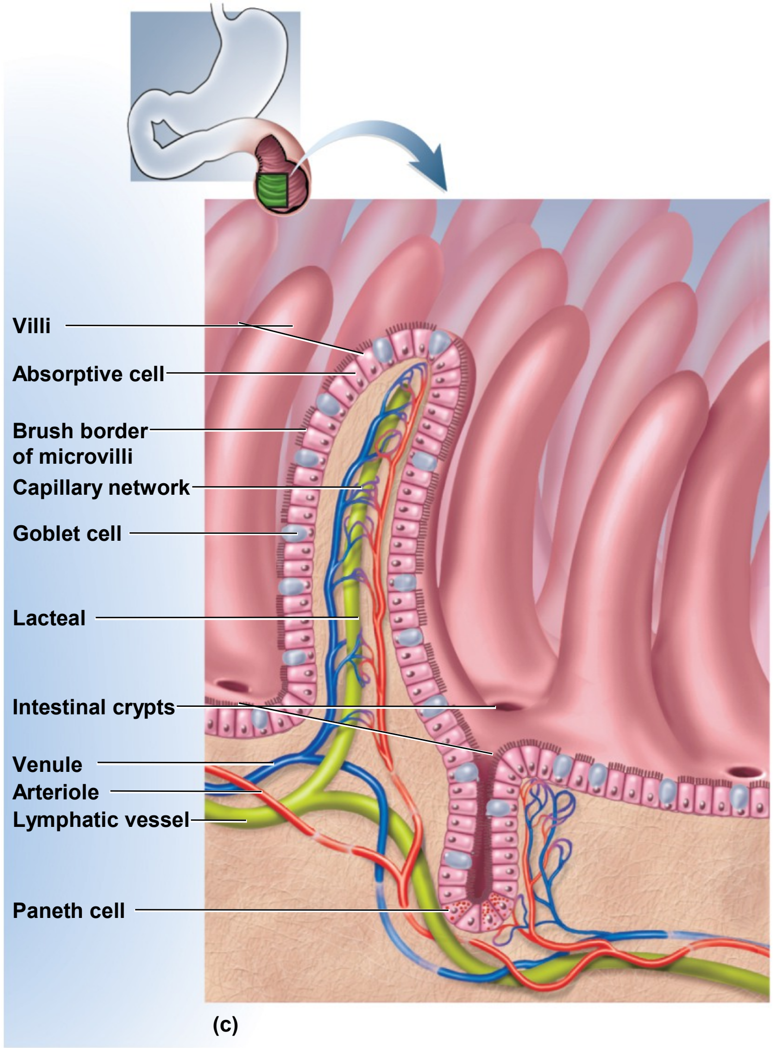
(b) Intestinal villi, photomicrograph (left) and illustration (right)

(c) Enterocyte with microvilli



(a)
Villi
Intestinal crypts
Muscularis mucosae
Duodenal glands
Muscularis externa
Serosa
(b)
0.5 mm
Villi
Absorptive cell
Brush border of microvilli
Capillary network
Goblet cell
Lacteal
Intestinal crypts
Venule
Arteriole
Lymphatic vessel
Paneth cell
(c)

Microscopic Anatomy



(c)

microvilli – fuzzy border of microvilli on apical surface of each absorptive cell

about 1 µm high

blood capillaries of villus absorb hydrophilic nutrients

lacteal absorbs most hydrophobic (lipids) packaged into chylomicrons

the **brush border** increases absorptive surface area

brush border enzymes – contained in the plasma membrane of epithelial cells with microvilli

brush border enzymes carry out some of the final stages of enzymatic digestion

not released into the lumen

contact digestion – the chyme must contact the brush border for digestion to occur

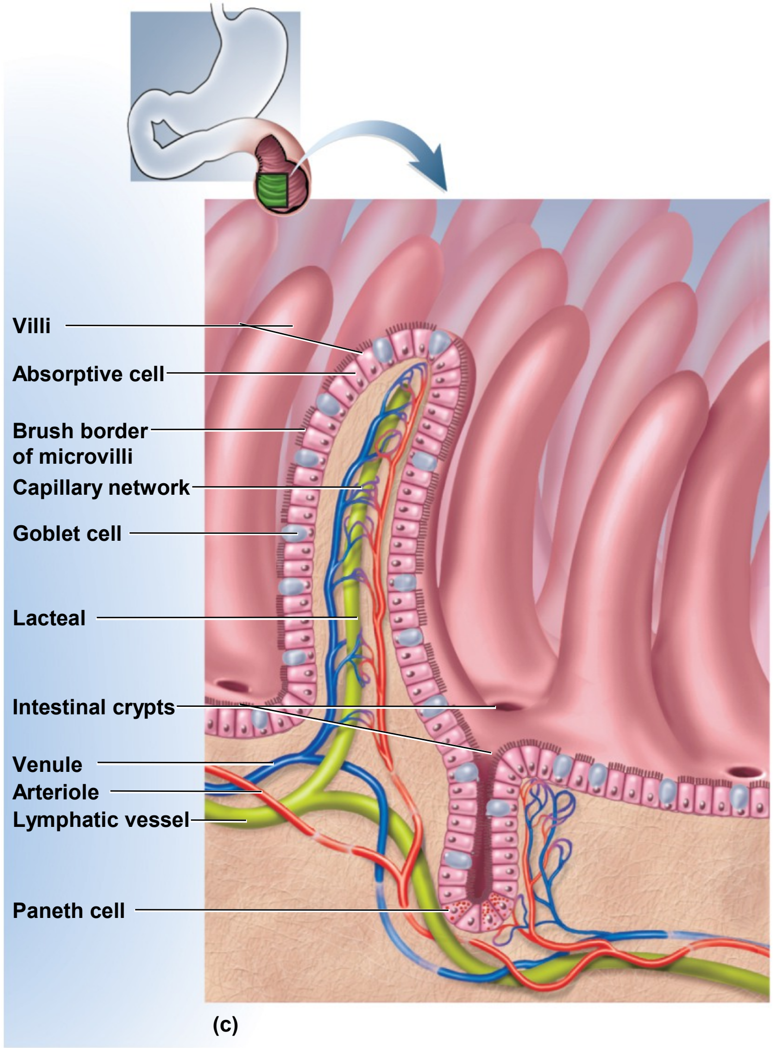
intestinal churning of chyme insures contact with the mucosa

Microscopic Anatomy

Microvilli

- fuzzy border of microvilli on apical surface of each absorptive cell
- about 1 µm high
- the brush border increases absorptive surface area
- brush border enzymes – contained in the plasma membrane of microvilli

- carry out some of the final stages of enzymatic digestion
- not released into the lumen
- contact digestion – the chyme must contact the brush border for digestion to occur
- intestinal churning of chyme insures contact with the mucosa



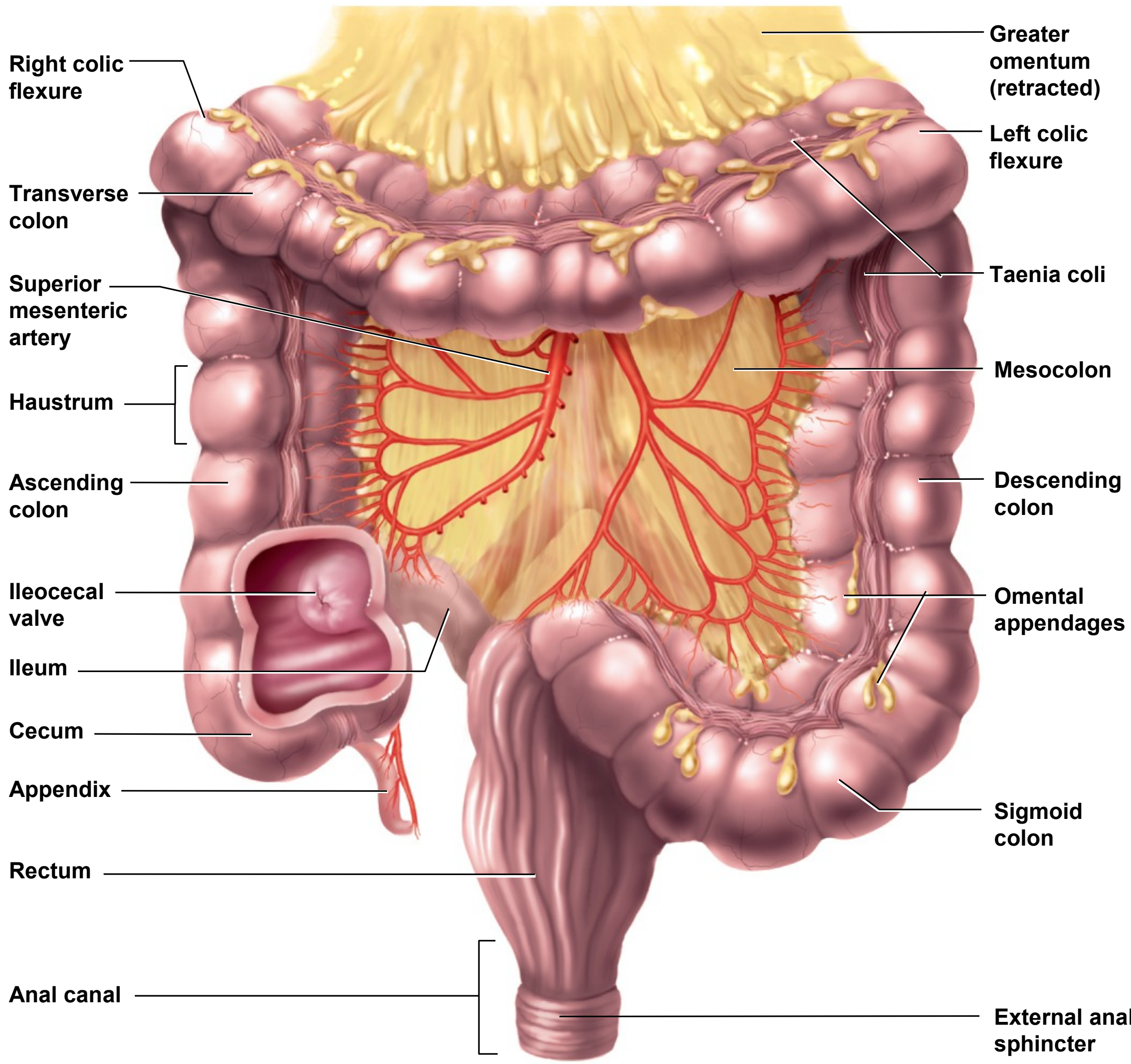
Intestinal Crypts (Crypts of Lieberkühn)

- Numerous pores that open into tubular glands on the floor of the small intestine between the bases of the villi
  - similar to gastric glands
  - in upper half, have **enterocytes** and **goblet** cells like the villi
  - in lower half, dominated by dividing **stem cells**
    - life span of 3 to 6 days // new epithelial cells migrate up the crypt to the tip of the villus where it is sloughed off and digested
  - a few **Paneth Cells** are clustered at the base of each crypt
    - secrete lysozyme, phospholipase, and defensins (defensive proteins that resist bacterial invasion of the mucosa)

Chemical Messengers of the Small Intestines

- Gastric glands, pyloric glands, and epithelial cells of the duodenum have various kinds of **enteroendocrine cells** that produce as many as <u>20 chemical messengers</u>
  - some are **hormones** enter blood and stimulate distant cells
  - others are **paracrine** secretions that stimulate neighboring cells
    - Some of these chemical messengers are peptides and are produced in both the digestive tract and the central nervous system /// these are called **gut-brain peptides**
      - substance P, vasoactive intestinal peptide (VIP), gastric inhibitory peptide (GIP), neuropeptide Y (NPY)
      - Secretin, cholecystokinin, gastric inhibiting peptide, and glucose dependent insulintropic peptide (secreted by duodenum / know the action of these enteroendocrine hormones)

Anatomy of Large Intestine



Gross Anatomy of Large Intestine

- Large intestine receives about 500 mL of indigestible residue per day
  - reduces it to about 150 mL of feces by absorbing water and salts
  - feces eliminated by using the **defecation reflex**

Large Intestine's Microscopic Anatomy

- Mucosa of large intestine
  - simple columnar epithelium through entire large intestine
  - anal canal has nonkeratinized stratified squamous epithelium in its lower half // provides abrasion resistance
- No circular folds or villi to increase surface area
- Intestinal crypts - glands sunken into lamina propria
- Greater density of mucous-secreting goblet cells
- Lamina propria and submucosal layers have large amount of lymphatic tissue /// provide protection from the bacteria that densely populate the LI

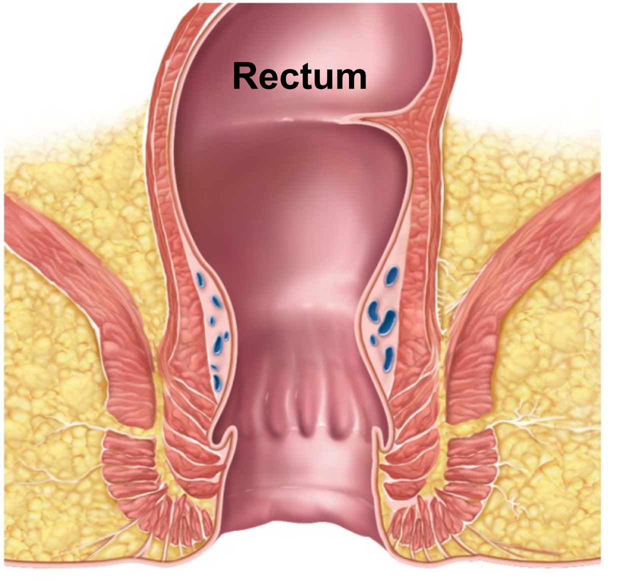
Distal End of the Large Intestine

– **Rectum**

- Stores fecal material prior to defication

- portion ending at anal canal

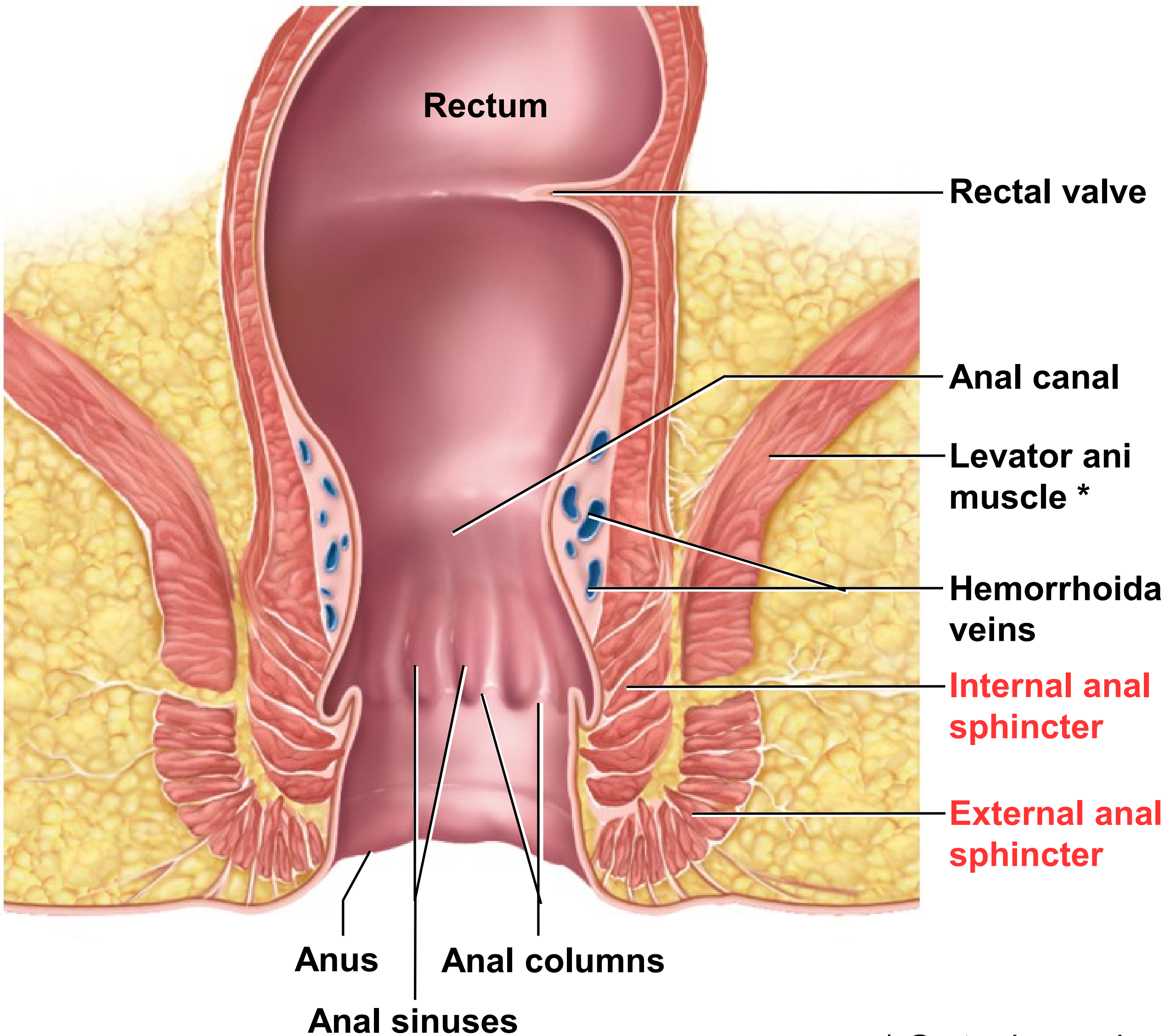
- has 3 curves and 3 infoldings the transverse rectal folds (rectal valves)



Gross Anatomy of Large Intestine

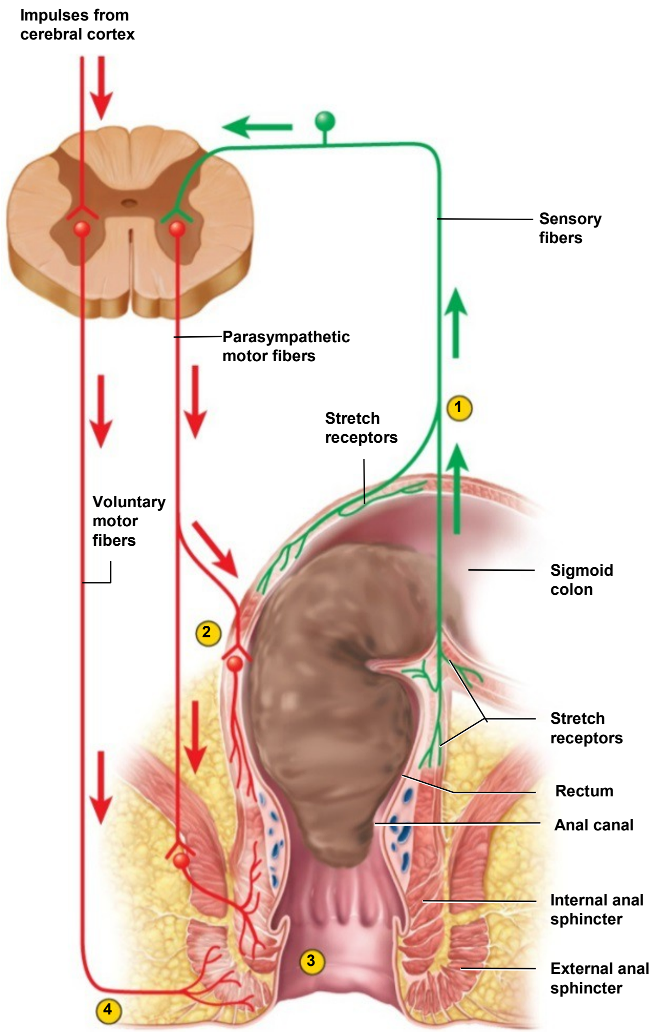
- Muscularis externa unusual structue
  - taenia coli – longitudinal fibers concentrated in three thicken, ribbon like strips
  - haustra – pouches in the colon caused by the muscle tone of the taenia coli
  - internal anal sphincter - smooth muscle of muscularis externa
  - external anal sphincter - skeletal muscle of pelvic diaphragm
  - omental (epiploic) appendages – club-like, fatty pouches of peritoneum adhering to the colon – unknown function

Anatomy of Anal Canal



* Go to dog park and watch a dog deficate to see this muscle's function!

Neural Control of Defecation



1. Feces stretch the rectum and stimulate stretch receptors, which transmit signals to the spinal cord.
2. A spinal reflex stimulates contraction of the rectum.
3. The spinal reflex also relaxes the internal anal sphincter.
4. Impulses from the brain prevent untimely defecation by keeping the external anal sphincter contracted. Defecation occurs only if this sphincter also relaxes.

1. filling of the rectum

2. reflex contraction of rectum and relaxation of internal anal sphincter

3. voluntary relaxation of external sphincter

Large Intestine Absorption and Motility

- Large intestine takes about 12 to 24 hours to reduce the residue of a meal to feces /// does not chemically change the residue *///* reabsorbs water and electrolytes
- **Feces** consist of 75% water and 25% solids - 30% bacteria, 30% undigested fiber, 10 – 20% fat, small amount of mucus and sloughed epithelial cells
- **Haustral contractions** occur every 30 minutes /// this kind of colonic motility is a form of segmentation /// distension of a haustrum stimulates it to contract
- **Mass movements** occur *1 to 3 times a day* *///* triggered by **gastrocolic** and **duodenocolic reflexes** *///* filling of the stomach and duodenum stimulates motility of the colon /// moves residue for several centimeters with each contraction

Bacterial Flora and Intestinal Gas

- **Bacterial flora** populate large intestine
  - about 800 species of bacteria
  - ferment cellulose and other undigested carbohydrates // we absorb resulting sugars
  - help in synthesis vitamins B and K
- **Flatus** - intestinal gas
  - 7 to 10 L of gas produced daily // Most reabsorbed
  - average person expels 500 mL per day (flatus) // most of this gas is swallowed air and odorless
  - bacteria produce hydrogen sulfide,methane, **indole** and **skatole** /// produce odor of flatus and feces // hydrogen gas may explode during electrical cauterization used in surgery

Accessory Organs of Digestive System

Teeth

Tongue

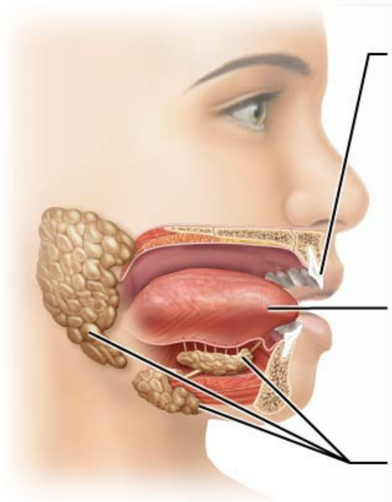
Salivary Glands

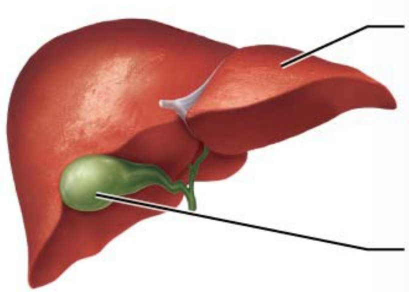
Liver

Pancreas

Gall Bladder

Summary of the structure and function of the accessory digestive organs.



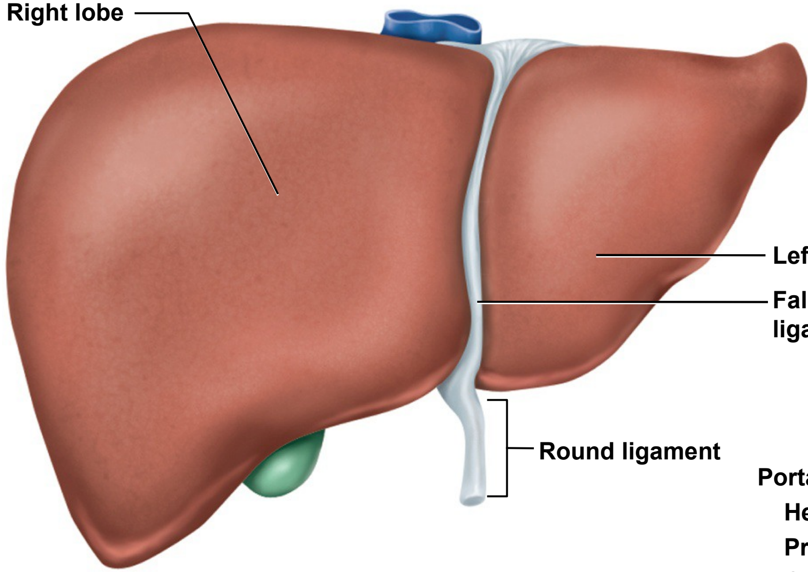


ORGAN	STRUCTURAL PROPERTIES	FUNCTIONAL ROLES
Teeth	• Two sets: primary and secondary dentition • Consist of a crown above the gum and a root embedded in bone • Composed of inner pulp cavity surrounded by dentin, which in turn is surrounded by enamel or cementum	• Mechanical digestion (mastication)
Tongue	• Consists of skeletal muscle with overlaying stratified squamous epithelium • Surface contains papillae	• Mechanical digestion • Propulsion (swallowing) • Sense of taste
Salivary glands	• Three sets: parotid glands, submandibular glands, and sublingual glands • Consist of mucous cells and serous cells	• Secrete saliva, which assists in chemical digestion, deters the growth of harmful microorganisms, and moistens food to assist in swallowing and mechanical digestion • Chemical digestion of carbohydrates
Pancreas	• Consists of pancreatic acini, composed of acinar cells surrounding a duct	• Secretes enzymes that catalyze chemical digestion of lipids, carbohydrates, proteins, and nucleic acids • Secretes bicarbonate ions to neutralize acidic chyme
Liver	• Consists of hexagonal liver lobules surrounding a central vein • Liver lobules contain plates of hepatocytes	• Mechanical digestion (via bile production) • Excretion (excretes wastes in bile)
Gallbladder	• Muscular sac on the posteroinferior liver	• Mechanical digestion (stores, concentrates, and releases bile)

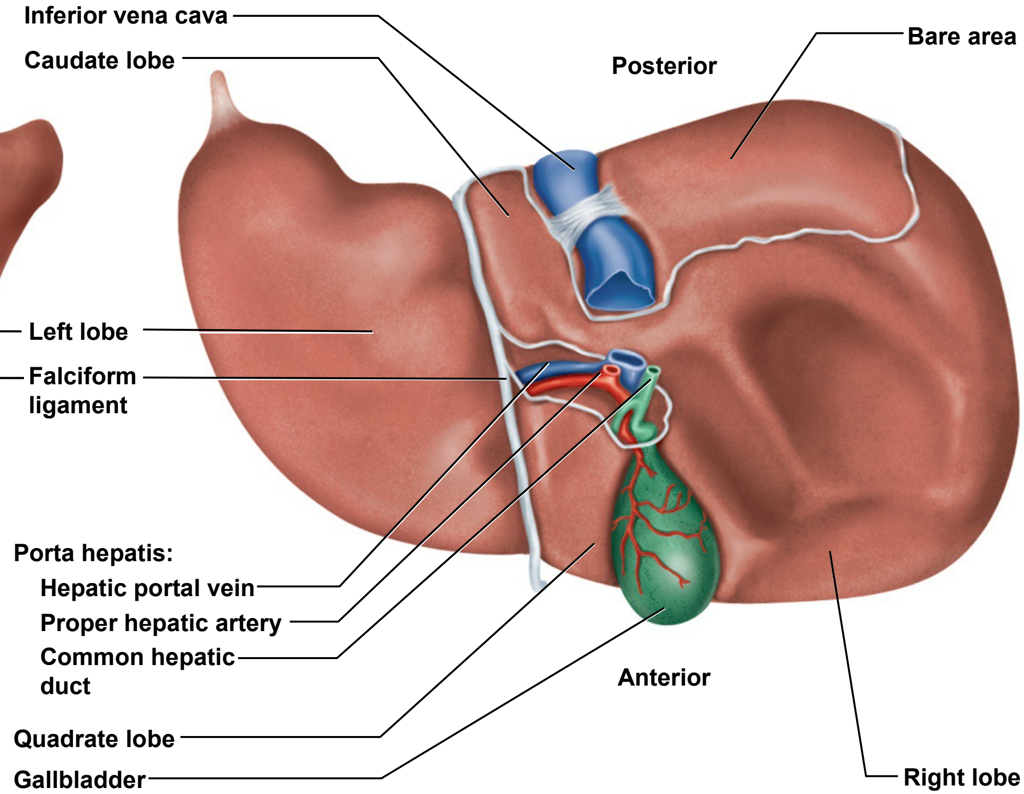
The Liver

- reddish brown gland located immediately inferior to the diaphragm
- body's largest gland // weighs about 1.4 kg (3 pounds)
- variety of critical functions
- **secretes bile** which contributes to digestion /// two major components = bile pigments and bile acids

Gross Anatomy of Liver



(b) Anterior view



(c) Inferior view

Functions of Hepatocytes

- After a meal, the hepatocytes absorb nutrients from the blood /// glucose, amino acids, iron, vitamins, and other nutrients for metabolism or storage (eg glycogen)

- Removes and degrades /// hormones, toxins, bile pigments, and drugs /// many macrophage in liver

- Secretes into the blood /// albumin, lipoproteins, clotting factors, activates angiotensin, complement proteins, and other products

- In between meals, hepatocytes breaks down stored glycogen and releases glucose into the blood

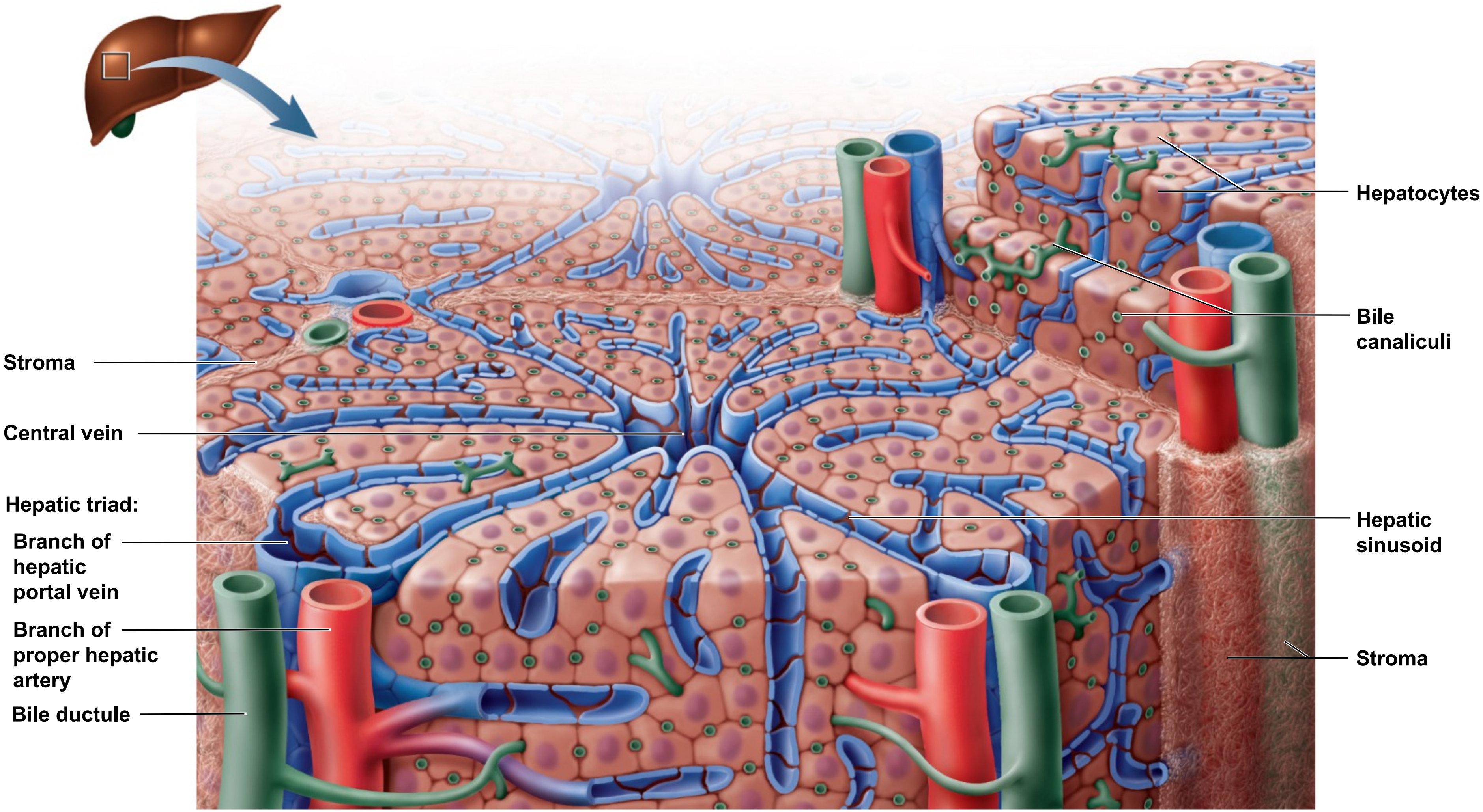
- Produces bile / bile transported to and stored in gall bladder

- Hepatocytes also able to preform gluconeogenisis and lipogenisis

Microscopic Anatomy of Liver

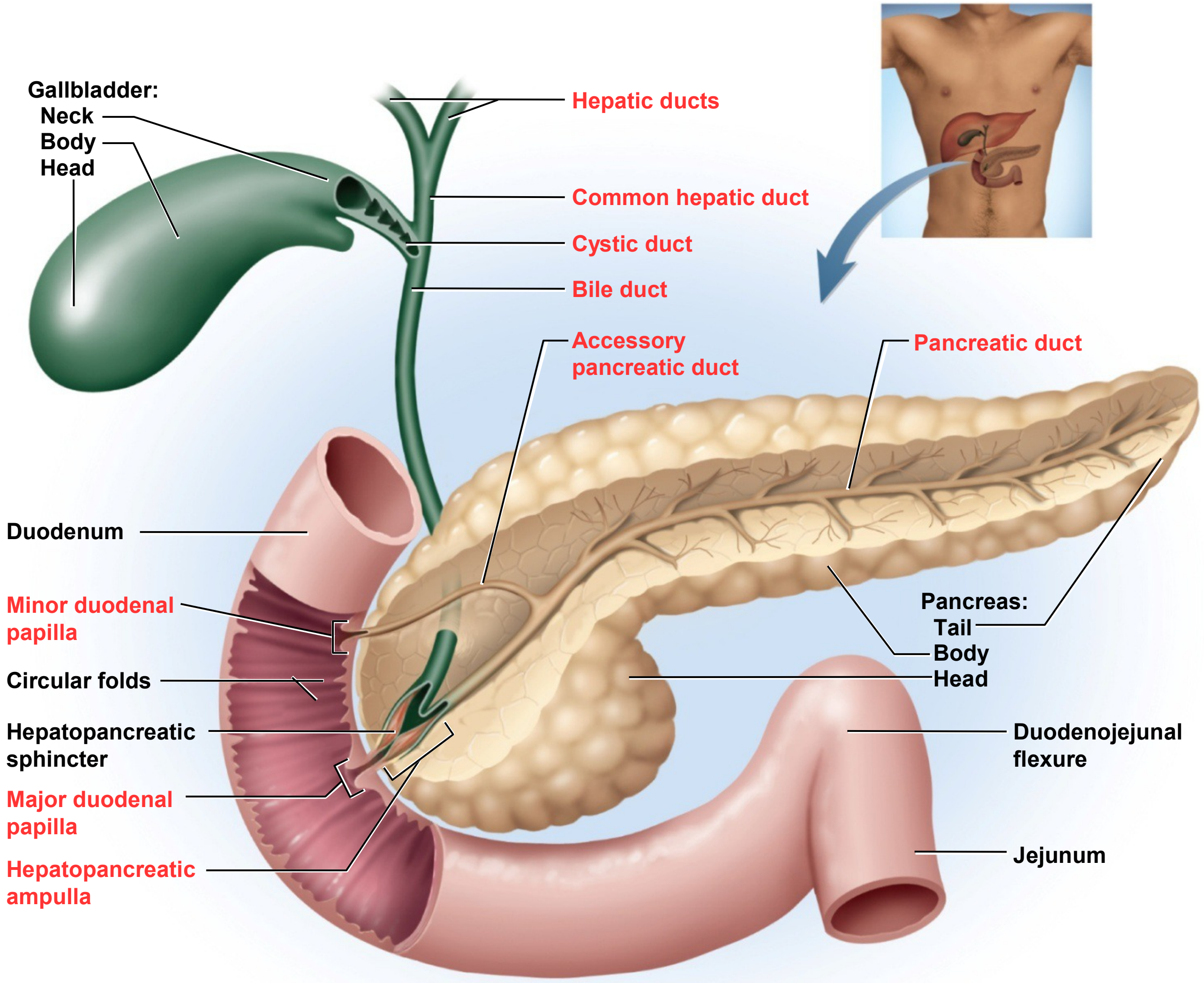
- **Bile canaliculi** – narrow channels into which the liver secretes bile
  - bile passes into bile **ductules** of the triads
  - ultimately into the **right and left hepatic ducts**
  - **common hepatic duct** – formed from convergence of right and left hepatic ducts on inferior side of the liver
  - **cystic duct** coming from gall bladder joins common hepatic duct

Microscopic Anatomy of Liver



(a)

Gross Anatomy of the Gallbladder, Pancreas, and Bile Passages



Bile

- Bile – yellow-green fluid containing minerals, cholesterol, neutral fats, phospholipids
  - Primary secretions are bile acids (also called salts) and bile pigments
  - liver secretes about 500 – 1000 ml of bile daily
  - bile gets to the gallbladder by first filling the bile duct but if hepatopancreatic papillae closed fluid fills gallbladder

Bile

Bile pigments **///** **bilirubin** – principal pigment derived from the **decomposition of hemoglobin** **///** bacteria in large intestine metabolize **bilirubin to urobilinogen** **///** responsible for the **brown color of feces**

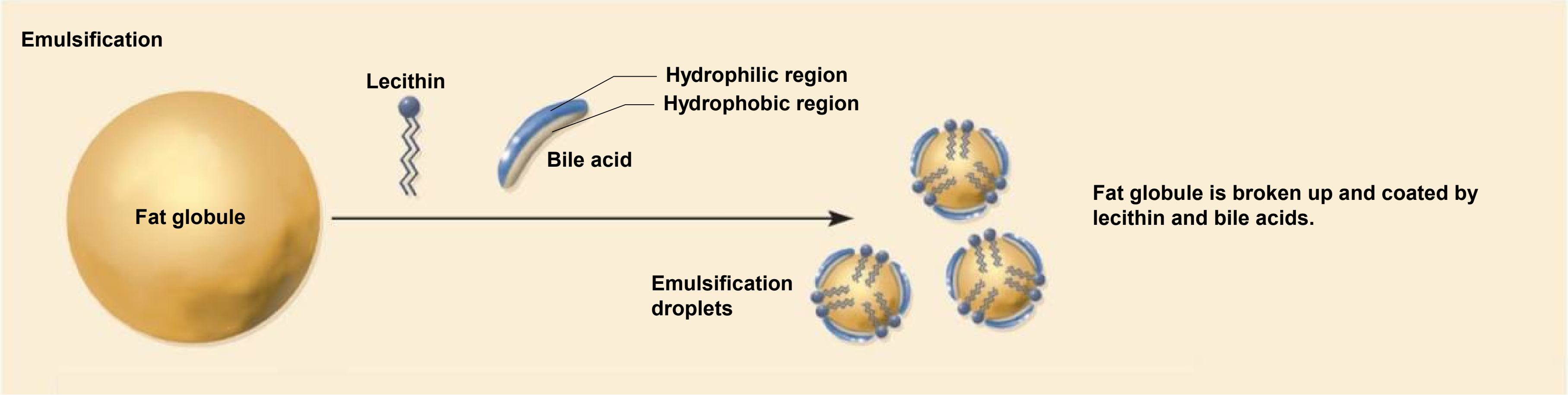
Bile acids (also called bile salts) /// steroids synthesized from cholesterol /// **gallstones** may form if bile becomes excessively concentrated

80% of bile acids are reabsorbed in the ileum and returned to the liver /// hepatocytes absorb and resecrete them /// **enterohepatic circulation** – this route secretion, reabsorption, and resecretion of bile acids two or more times during digestion of an average meal

20% of the bile acids are excreted in the feces **///** this is the body's only way of eliminating excess cholesterol /// liver synthesizes new bile acids from cholesterol to replace those lost in feces

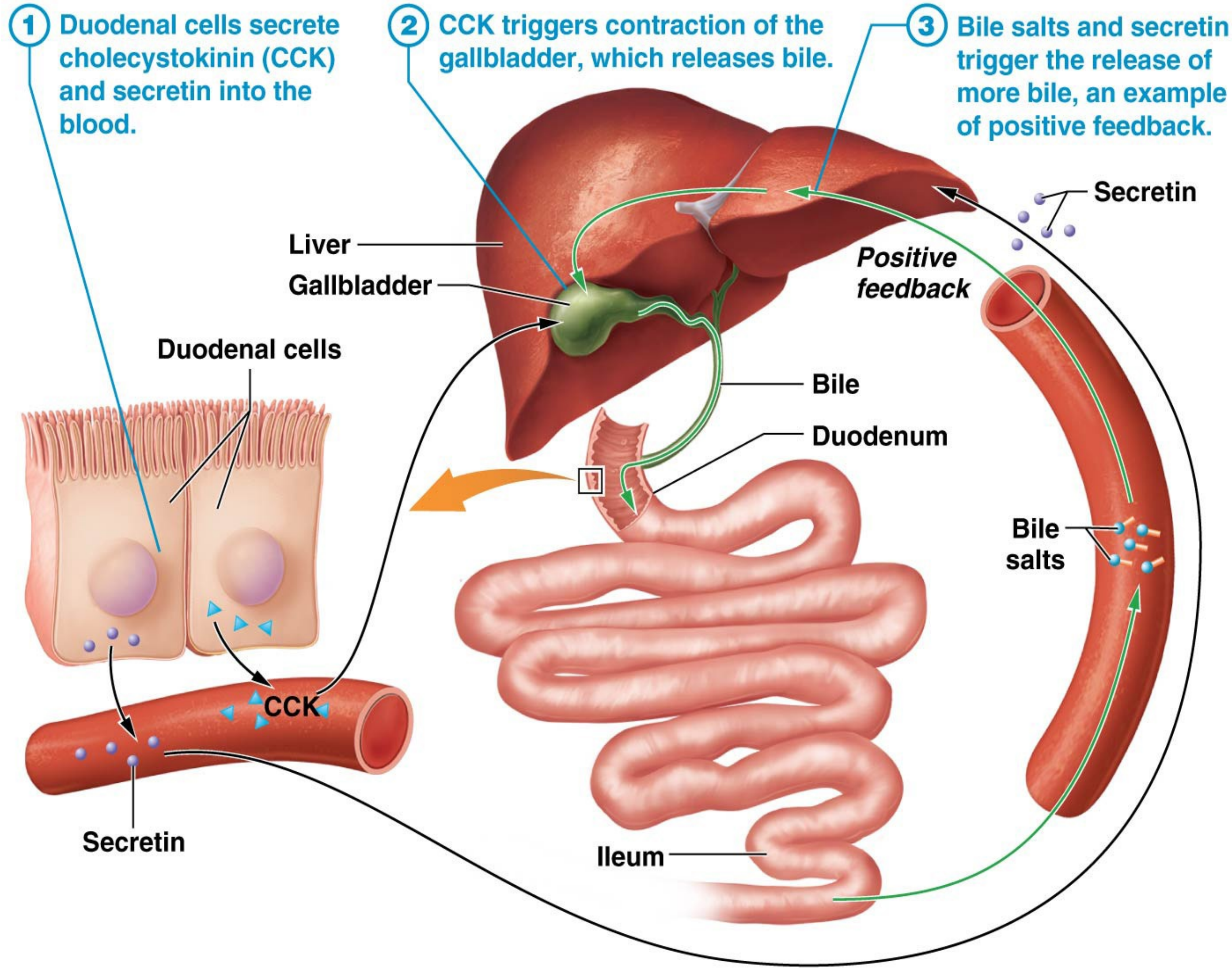
Another molecule associated with the bile acids is **lecithin**, a phospholipid that helps in fat digestion and absorption

Emulsification
Action of Bile Acids and Lethin



More on this topic covered in metabolism.

Secretion of Bile



Note: Secretin also stimulate cells lining pancreatic ducts and bile duct to secrete bicarbonate. Why?

The Pancreas

- Spongy retroperitoneal gland posterior to the greater curvature of the stomach
  - measure 12 to 15 cm long, and 2.5 cm thick
  - has head encircled by duodenum, body, midportion, and a tail on the left
  - both an endocrine and exocrine gland
    - endocrine portion – pancreatic islets that secrete insulin and glucagon
    - exocrine portion – 99% of pancreas that secretes 1200 to 1500 mL of pancreatic juice per day /// secretory acini release their secretion into small ducts that converge on the main pancreatic duct

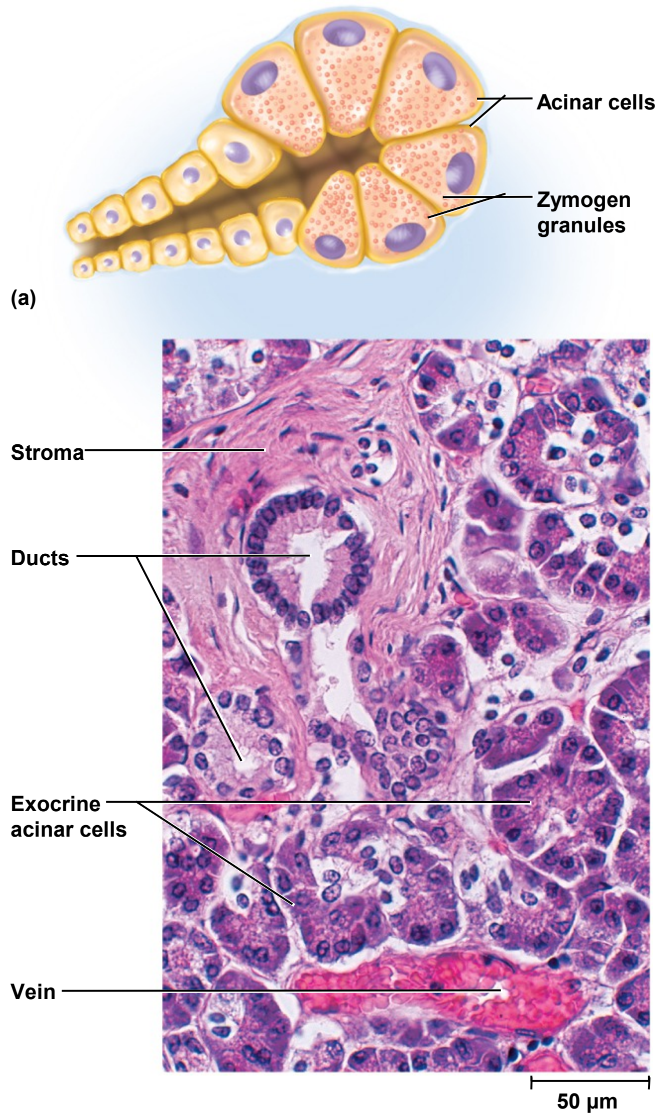
The Pancreas

- **Pancreatic duct** runs lengthwise through the middle of the gland
    - joins the bile duct at the **hepatopancreatic ampulla**
    - **hepatopancreatic sphincter** controls release of both bile and pancreatic juice into the duodenum
- **Accessory pancreatic duct**
    - smaller duct that branches from the main pancreatic duct
    - opens independently into the duodenum
    - **bypasses the sphincter** and allows <u>pancreatic juice to be released into the duodenum even when bile is not</u>

The Pancreas

- **Pancreatic juice** – alkaline mixture of water, enzymes, zymogens, sodium bicarbonate, and other electrolytes
  - acini secrete the enzymes and zymogens
  - **ducts** secrete bicarbonate /// required in order to **buffer HCl** from the stomach

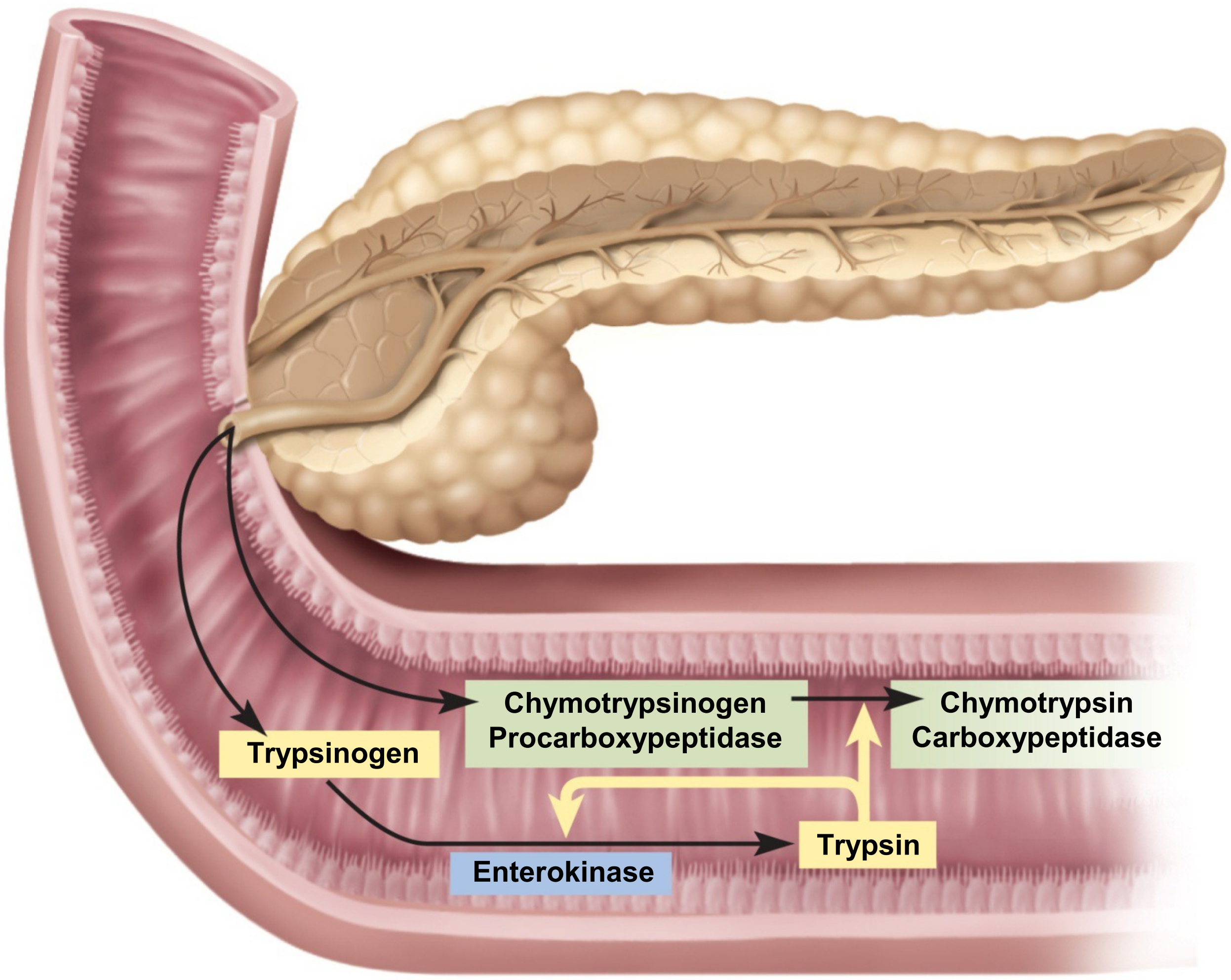
Pancreatic Acinar Cells



Pancreatic Proteolytic Zymogens

- Trypsinogen
  - secreted into intestinal lumen
  - converted to trypsin by enterokinase // this is a , brush boader enzyme of small intestine's mucosa
  - trypsin is autocatalytic – this means it converts trypsinogen into still more trypsin
  - trypsin = proteinolytic enzyme
- Chymotrypsinogen /// this is converted to trypsinogen by trypsin
- Procarboxypeptidase /// this is converted to carboxypeptidase by trypsin

Activation of Pancreatic Enzymes in the Small Intestine



Other Pancreatic Enzymes

- **Pancreatic amylase** – digests starch
- **Pancreatic lipase** – digests fat
- **Ribonuclease** and **deoxyribonuclease** – digest RNA and DNA respectively

Regulation of Pancreatic & Gall Bladder Secretion (1 of 2)

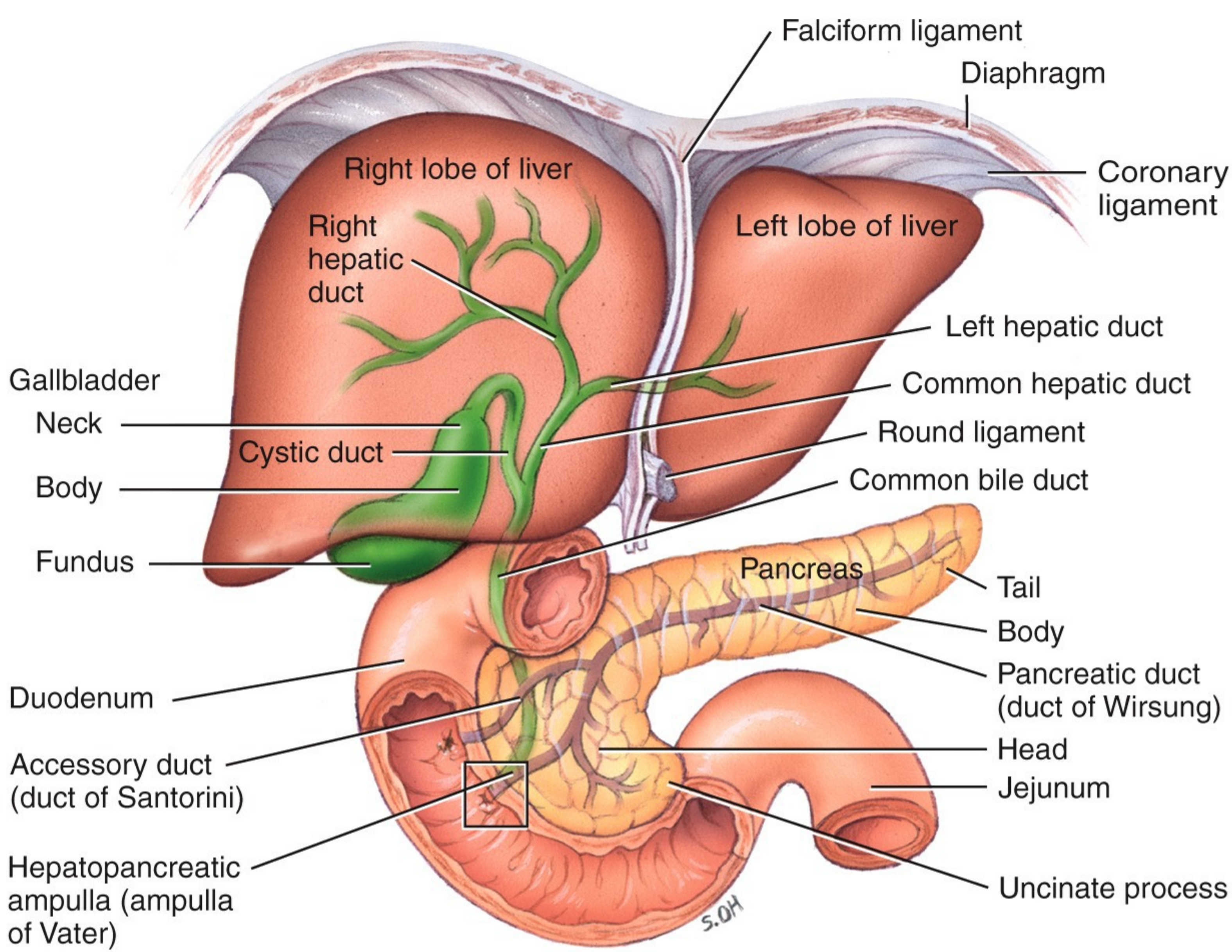
- **Three stimuli** are chiefly responsible for the release of **pancreatic and bile secretions**
  - 1.) acetylcholine
  - 2. cholecystokinin
  - 3. secretin
- **Acetylcholine (ACh) -** from vagus nerves and enteric nerves
  - stimulates acini to secrete their enzymes during the cephalic phase of gastric control even before food is swallowed
  - enzymes remain in acini and ducts until chyme enters the duodenum

How Pancreatic & Gall Bladder Secretion Regulated (2 of 2)

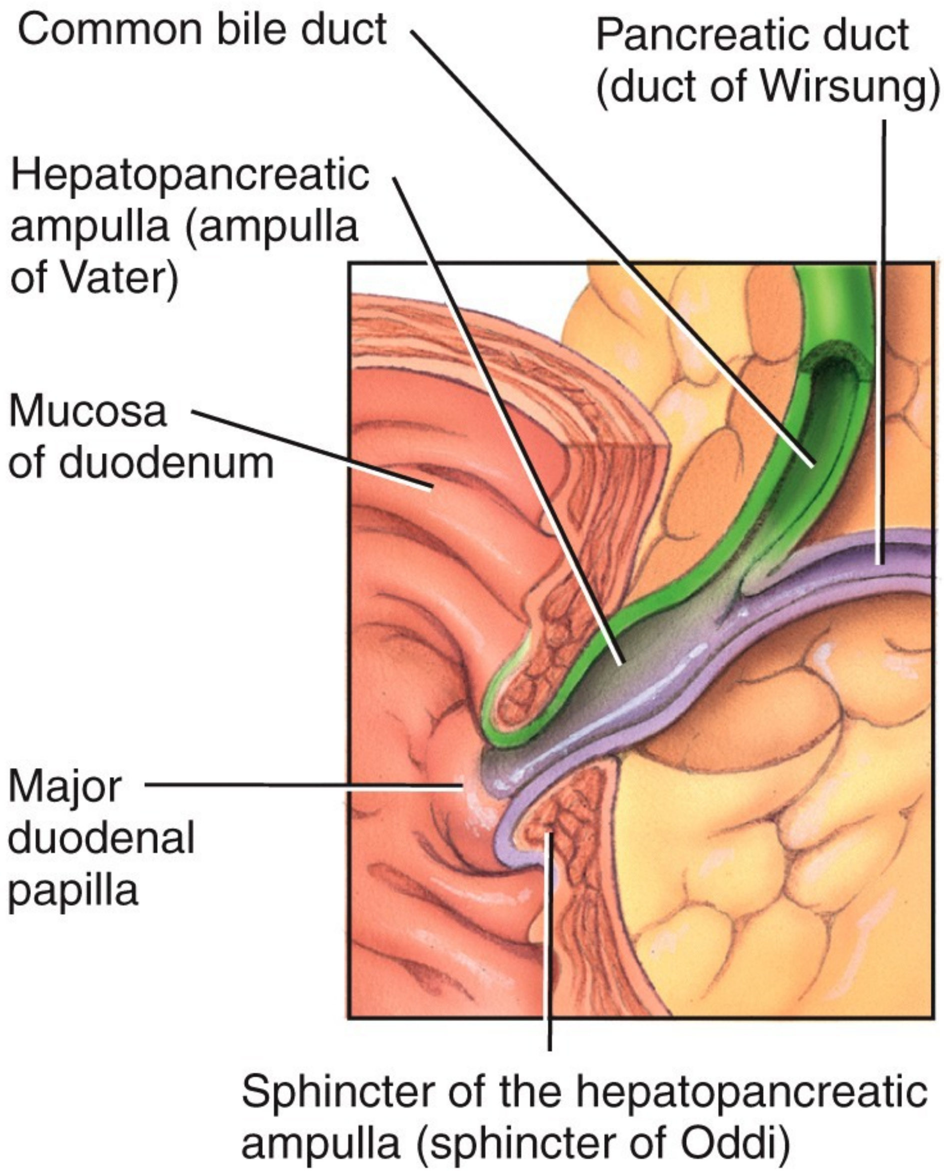
- **Cholecystokinin (CCK) -** secreted by mucosa of duodenum in response to arrival of fats in small intestine
  - stimulate pancreatic acini cells to **secrete digestive enzymes**
  - strongly stimulates gall bladder to release bile
  - induces relaxation of hepatopancreatic sphincter that allows both bile and pancreatic digestive enzymes into the duodenum
- **Secretin -** released from duodenum in response to acidic chyme arriving from the stomach
  - stimulates ducts in both liver and pancreas **to secrete more sodium bicarbonate**
  - raising pH to level pancreatic and intestinal digestive enzymes require

Gallstones

- **gallstones (biliary calculi)** - hard masses develop in either the gallbladder or bile ducts
  - composed of cholesterol, calcium carbonate, and bilirubin
  - gallstones may cause obstruction within ducts // very painful // prevents essential molecules for proper fat metabolism from reaching the duodenum
  - cause jaundice - yellowing of skin and sclera due to bile pigment accumulation, poor fat digestion, and impaired absorption of fat-soluble vitamins
- **lithotripsy** - use of ultrasonic vibration to pulverize stones without surgery
- **cholelithiasis** - formation of gallstones /// most common in obese women over 40 due to excess cholesterol



(a) Anterior view



(b) Details of hepatopancreatic ampulla

2004: Overweight,
Multiple Health Issues
2006: Jaundice
From Liver Disease
2014: 100% RECOVERED
AND HEALTHY!