Unit 10:
The
Digestive & Excretory
Systems

Ms. Randall

Lesson 1:

Objective:

Describe the four fundamental tissue layers of the alimentary canal

Explain the process of digestion

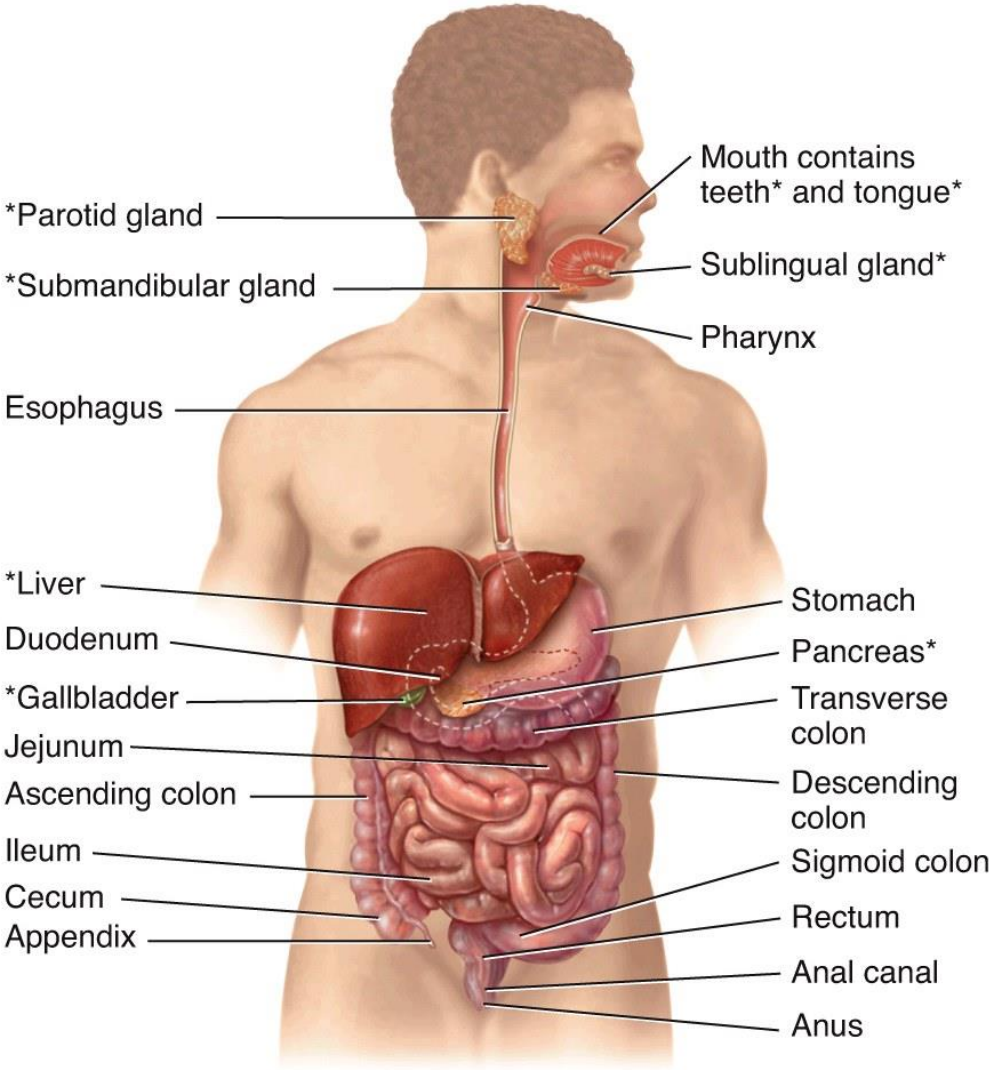
Relate the nervous and endocrine systems to the regulation of digestion.

Digestive System

- Anatomy
  - Gastrointestinal (GI) tract
    - Mouth, pharynx, esophagus, stomach, small intestine, and large intestine
  - Accessory digestive organs
    - Teeth, tongue, salivary glands, liver, gallbladder, and pancreas
- Functions
  - Ingestion
  - Secretion
  - Mixing and propulsion
  - Digestion
    - Mechanical
    - Chemical
  - Absorption
  - Defecation

Function of the digestive system

- Break down the foods you eat
- Release their nutrients
- Absorb those nutrients into the body



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

Table 1. Contribution of Other Body Systems to the Digestive System

Body system	Benefits received by the digestive system
Cardiovascular	Blood supplies digestive organs with oxygen and processed nutrients
Endocrine	Endocrine hormones help regulate secretion in digestive glands and accessory organs
Integumentary	Skin helps protect digestive organs and synthesizes vitamin D for calcium absorption
Lymphatic	Mucosa-associated lymphoid tissue and other lymphatic tissue defend against entry of pathogens; lacteals absorb lipids; and lymphatic vessels transport lipids to bloodstream
Muscular	Skeletal muscles support and protect abdominal organs
Nervous	Sensory and motor neurons help regulate secretions and muscle contractions in the digestive tract
Respiratory	Respiratory organs provide oxygen and remove carbon dioxide
Skeletal	Bones help protect and support digestive organs
Urinary	Kidneys convert vitamin D into its active form, allowing calcium absorption in the small intestine

Layers of the GI Tract

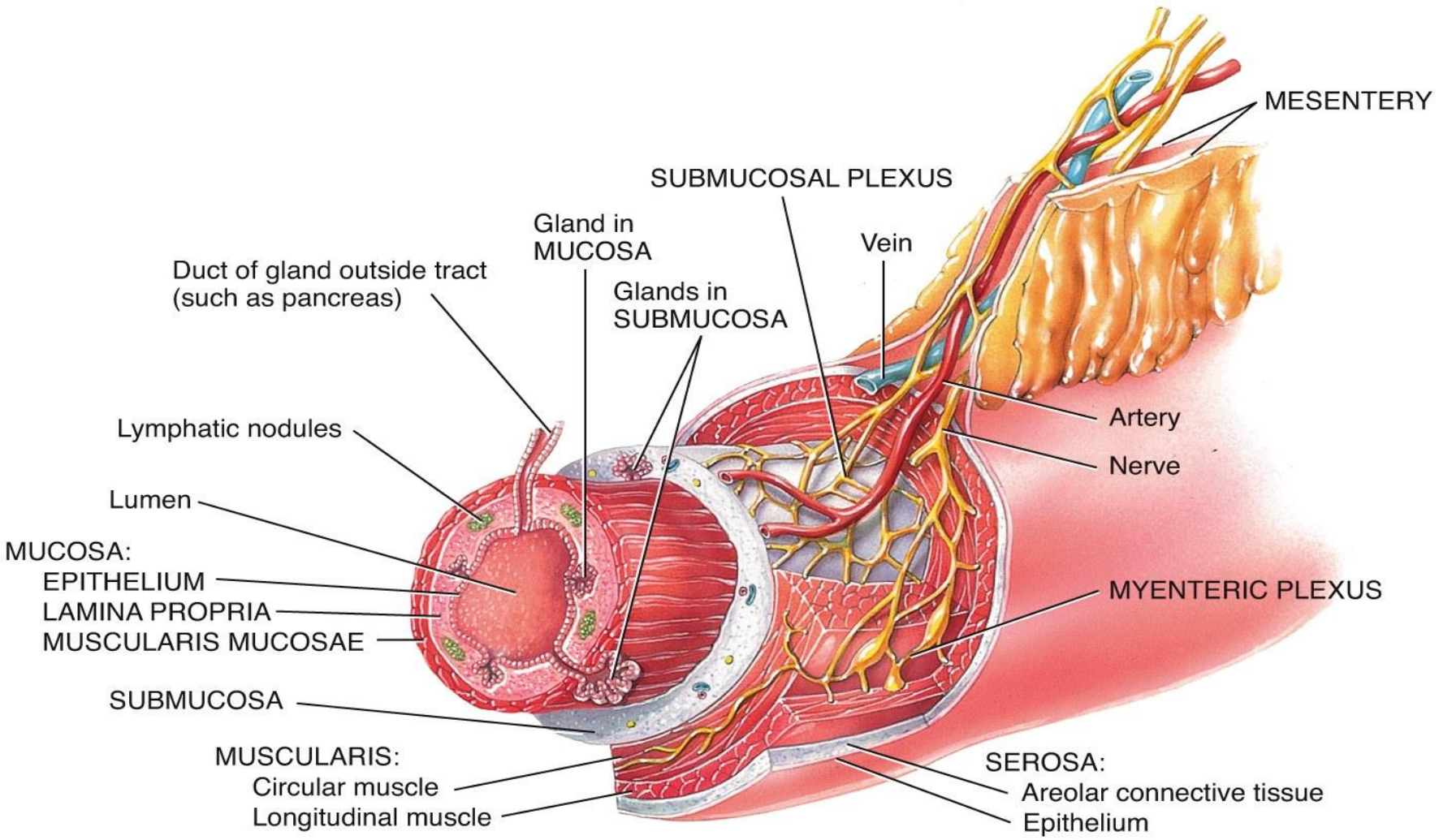
Four-layered arrangement of tissues in wall

- Mucosa
  - Epithelium – type varies along length of GI tract, including glandular and enteroendocrine cells
  - Lamina propria – supportive areolar connective layer with blood and lymph vessels and MALT
  - Muscularis mucosa – thin smooth muscle that creates folds to increase surface area
- Submucosa
  - Areolar connective tissue with many blood and lymph vessels and submucosal neuron plexus

Layers of the GI Tract

- Muscularis
  - Skeletal muscle in mouth, pharynx, and superior and middle parts of esophagus for swallowing
  - Smooth muscle in rest of tract
    - Two sheets most – inner circular and outer longitudinal
    - Three sheets in stomach – additional oblique
- Serosa
  - Superficial areolar and simple squamous epithelium layer
    - Adventitia superior to diaphragm
    - Visceral peritoneum inferior to diaphragm

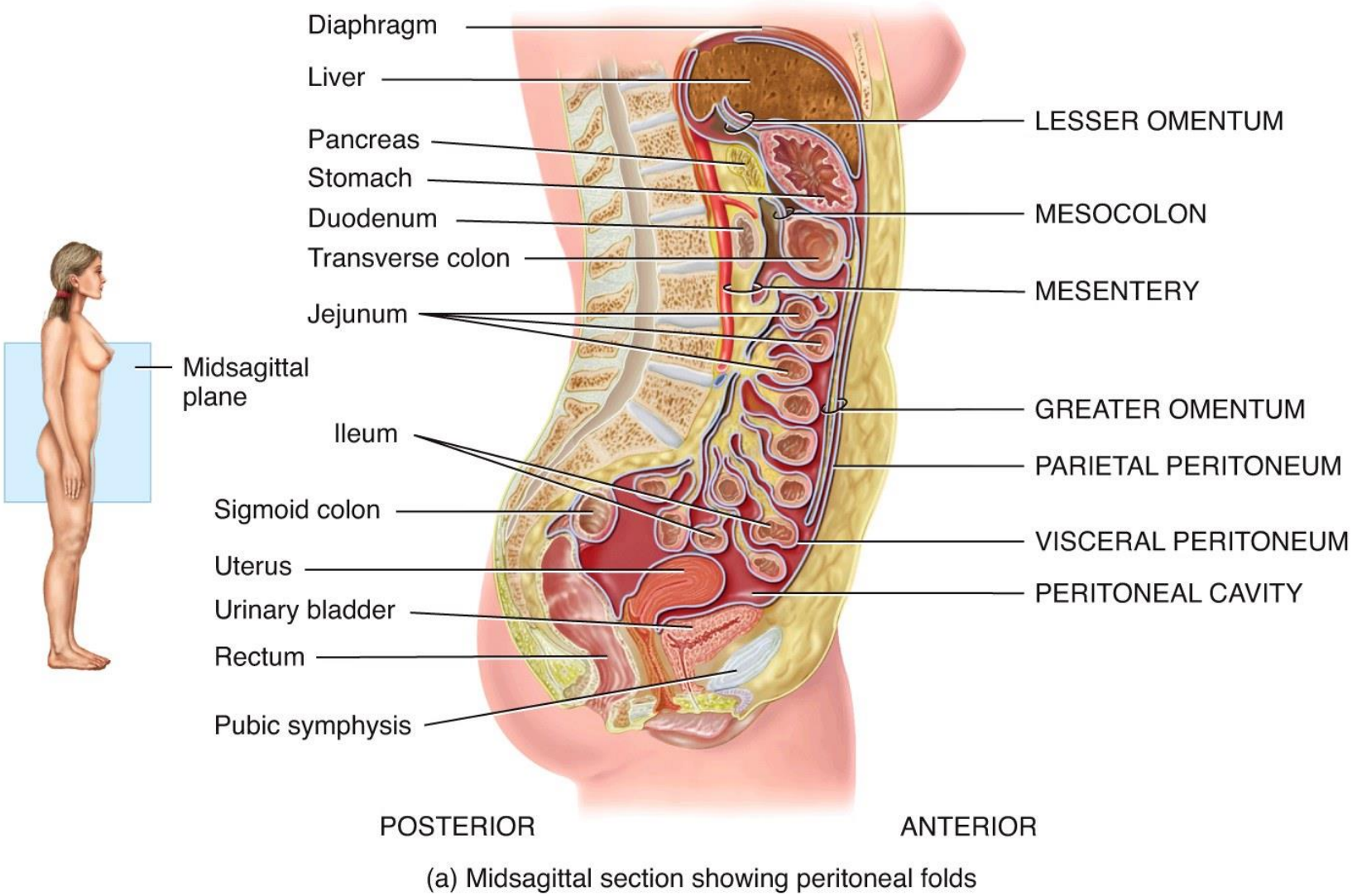
Layers of the GI Tract



Peritoneum

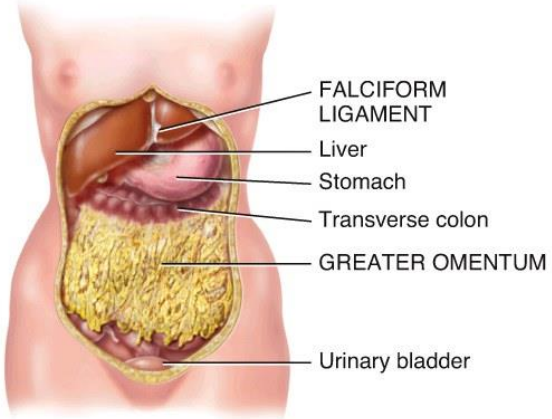
- Largest serous membrane in body
  - Parietal peritoneum lines abdominopelvic cavity
  - Visceral peritoneum covers organs
  - Peritoneal cavity contains serous fluid between two serous membranes
  - Retroperitoneal – some organs outside peritoneal cavity, but inside abdominopelvic cavity; covered only anteriorly by peritoneum (kidneys, pancreas)
- Large folds between organs support and contain blood and lymph vessels and nerves
  - Greater omentum, falciform ligament, lesser omentum, mesentery, mesocolon

Peritoneum

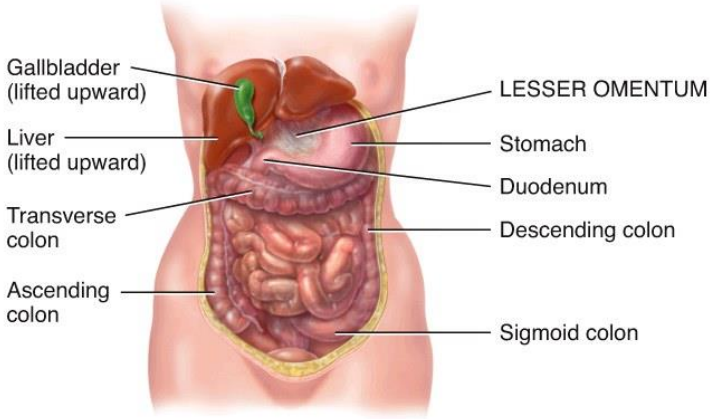


(a) Midsagittal section showing peritoneal folds

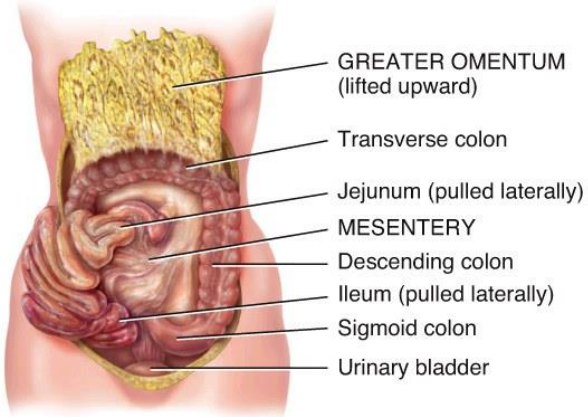
Peritoneum



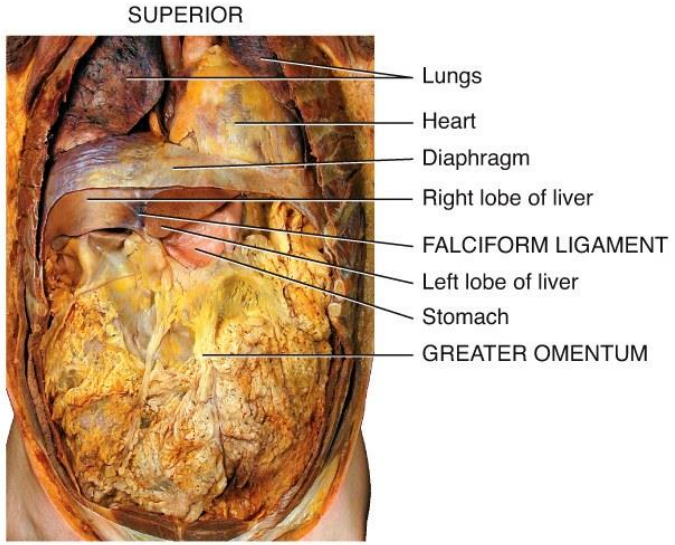
(b) Anterior view



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



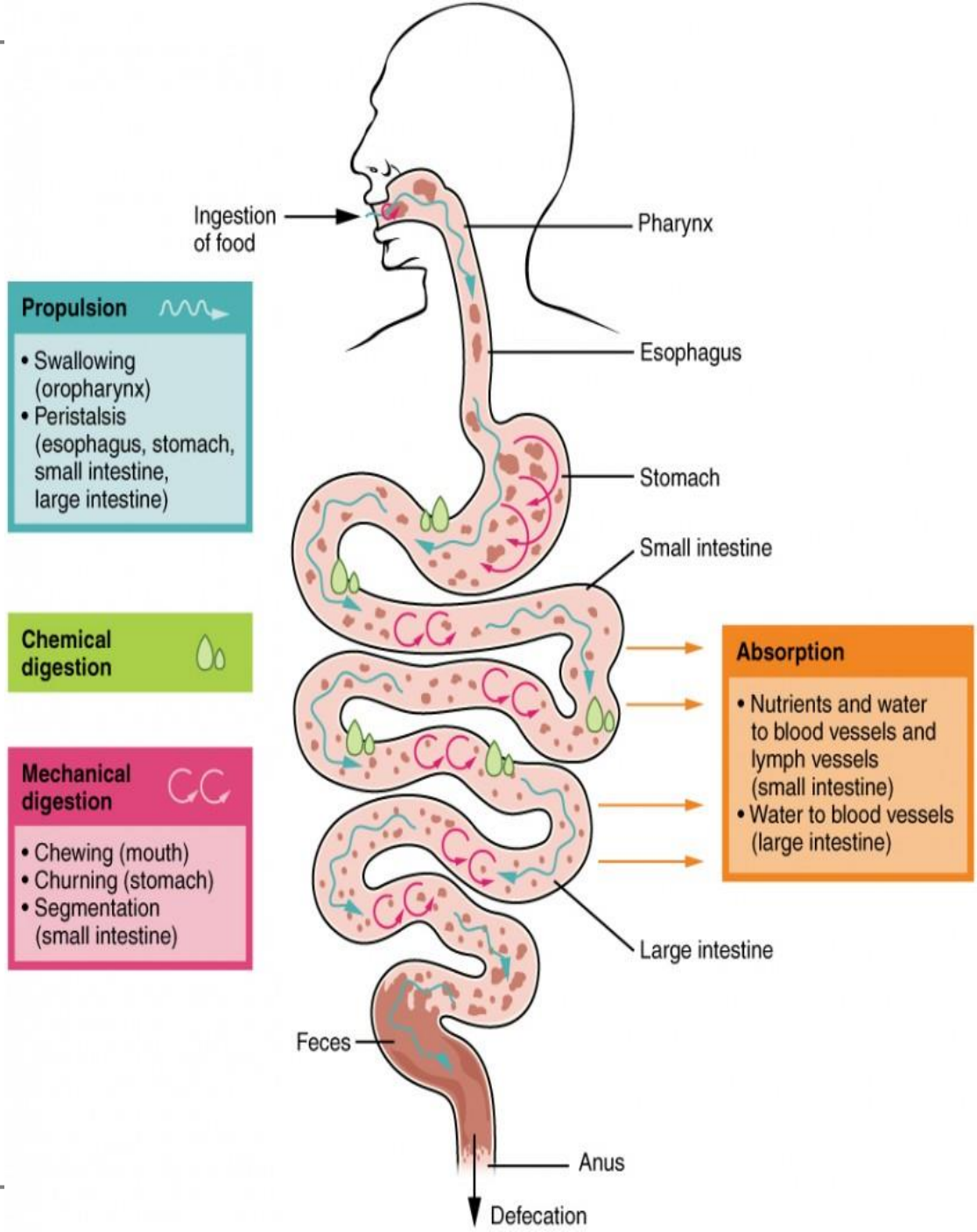
(d) Anterior view (greater omentum lifted and small intestine reflected to right side)



(e) Anterior view

Digestion

- Phases Include
  1. Ingestion
  2. Movement
  3. Mechanical and Chemical Digestion
  1. Absorption
  2. Elimination



Digestion

- Types
  - Mechanical (physical)
    - Chew
    - Tear
    - Grind
    - Mash
    - Mix
  - Chemical
    - Enzymatic reactions to improve digestion of
      - Carbohydrates
      - Proteins
      - Lipids

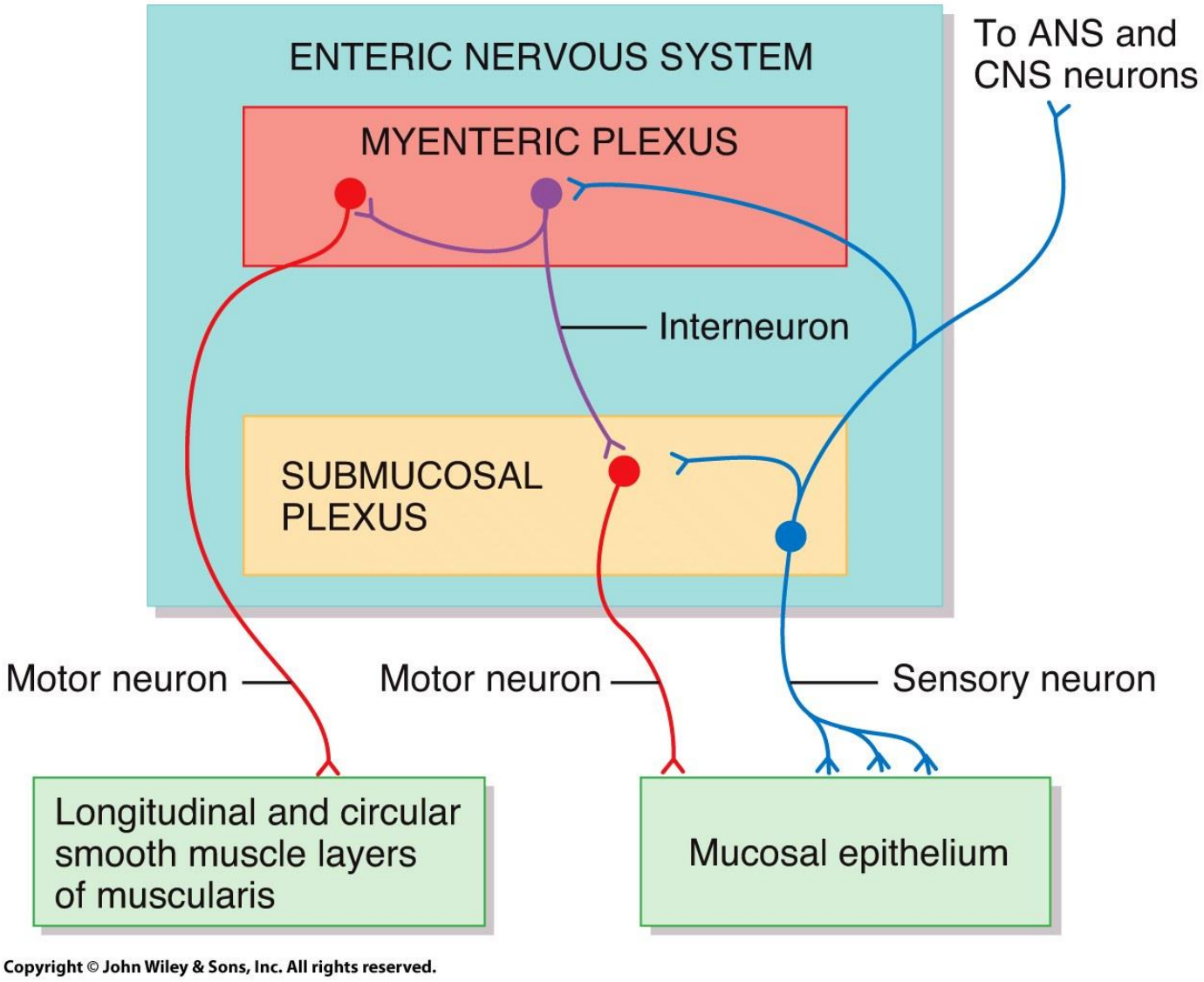
Digestive Phases

- Cephalic phase
  - Salivary glands secrete saliva and gastric glands secrete gastric juice to prepare mouth and stomach for food
- Gastric phase
  - Stomach peristalsis and gastric gland secretion of gastric juice in response to presence of food in stomach for mechanical and chemical digestion
- Intestinal phase
  - Coordinated intestinal peristalsis and intestinal and accessory organ secretions in response to food entering duodenum for digestion and absorption

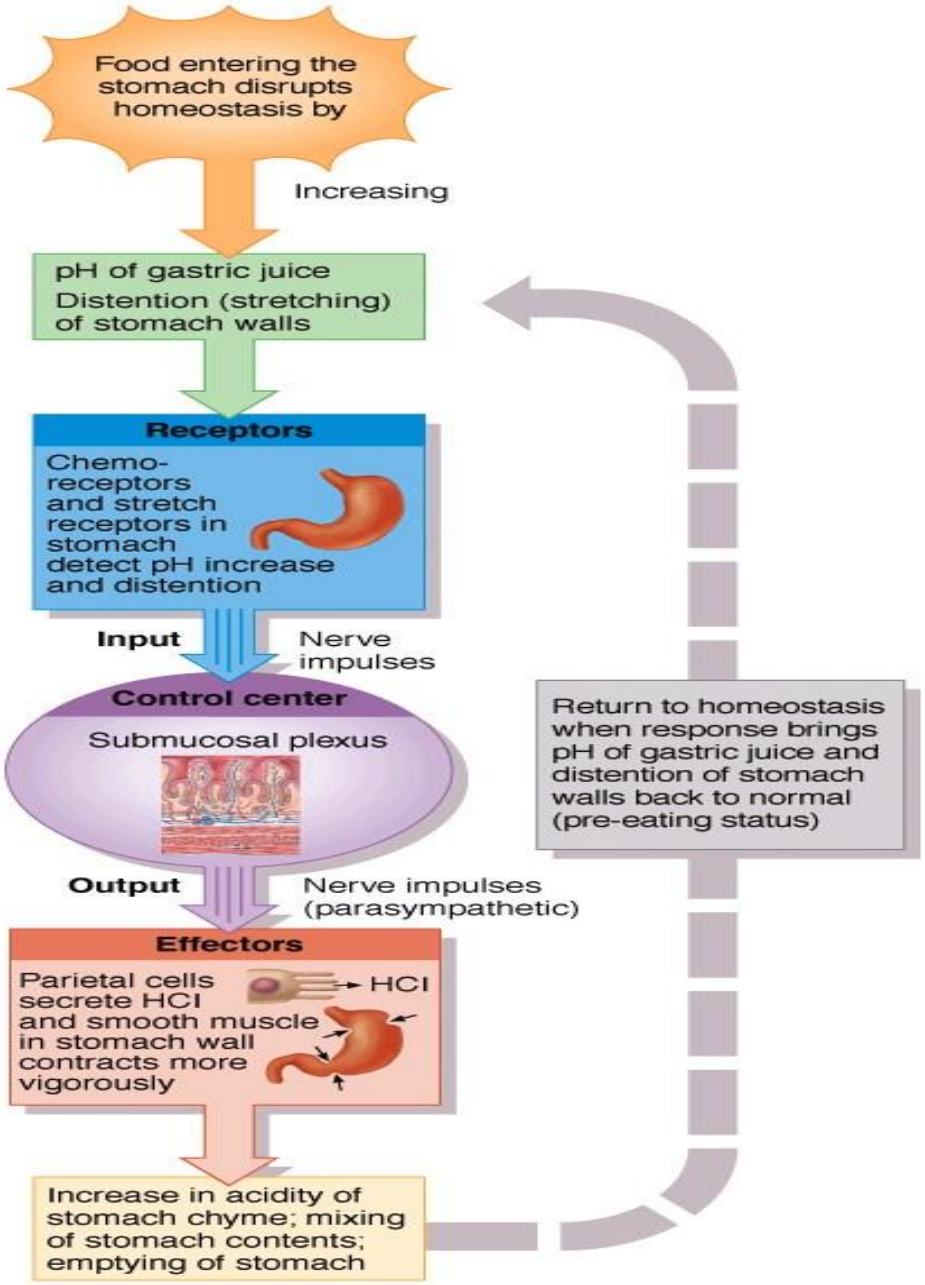
Neural Innervation of GI Tract

- Enteric nervous system – intrinsic sensory and motor neurons that regulate GI tract independently and with reflex pathways
  - Sensory receptors – chemoreceptors and stretch receptors in mucosal epithelium
  - Neurons arranged into two plexuses
    - Myenteric – in muscularis layer; controls GI tract motility
    - Submucosal – in submucosa; controls secretions
- Autonomic nervous system
  - Parasympathetic – increases secretion and motility
  - Sympathetic – decreases secretion and motility

Neural Innervation of GI Tract



Neural Regulation of Gastric Phase



Hormonal Regulation of Digestive Phases

- Gastric phase
  - Gastrin from gastric enteroendocrine cells
    - Release stimulated by stomach distention, high pH, presence of partially digested proteins in stomach
    - Stimulates gastric glands, contracts lower esophageal sphincter, increases motility, and relaxes pyloric sphincter

Hormonal Regulation of Digestive Phases

- Intestinal phase
  - Secretin from intestinal enteroendocrine cells
    - Release stimulated by acidic chyme in duodenum
    - Stimulates bicarbonate ion-rich pancreatic juice and inhibits gastric juice secretion
  - Cholecystokinin (CCK)
    - Release stimulated by chyme containing amino acids and fatty acids
    - Stimulates enzyme-rich pancreatic juice, contraction of gallbladder to release stored bile through cystic duct and common bile duct, contracts pyloric sphincter to slow gastric emptying
    - Acts on hypothalamus to produce satiety feeling

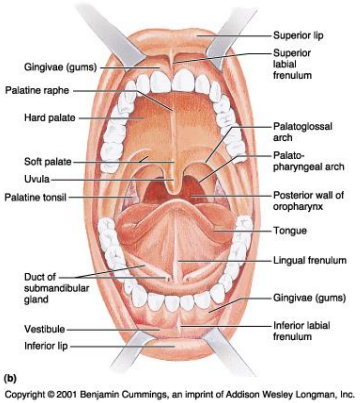
Lesson 2: Anatomy of the Digestive System

Objective:

Identify the organs of the alimentary canal from proximal to distal, and briefly state their function

Identify the accessory digestive organs and briefly state their function

Mouth



- Mastication (chewing)
  - Mechanical digestion and mixes food with saliva
  - Shapes into soft, flexible bolus for swallowing
- Chemical digestion
  - Salivary **amylase** begins digestion of starches to disaccharides
  - Lingual **lipase** will break down dietary triglycerides into fatty acids and diglycerides once it reaches acidic environment of stomach

Pharynx

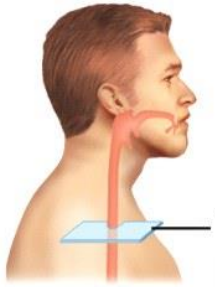
- Funnel-shaped tube that extends from internal nares to esophagus posteriorly, and to the larynx anteriorly
  - Nasopharynx functions in respiration only
  - Both oropharynx and laryngopharynx shared digestive and respiratory functions
  - Skeletal muscle contractions help propel food to esophagus during deglutition (swallowing)

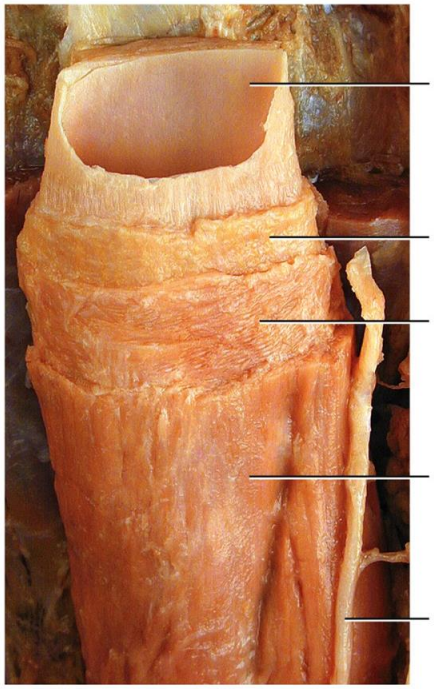
Epiglottis is a flap-like structure at the back of the throat that closes over the trachea preventing food from entering it. It is located in the Pharynx.

Esophagus

- Collapsible, smooth muscle tube that connects the pharynx to the stomach for transport
  - Upper esophageal sphincter – regulates movement of food from pharynx into esophagus
  - Lower esophageal sphincter – regulates movement of food from esophagus to stomach, and prevents regurgitation of acidic stomach contents
  - Esophageal hiatus – opening in diaphragm, passing from mediastinum to stomach in abdomen
  - **Mucus secreted for lubrication, but no enzymes and no absorption**

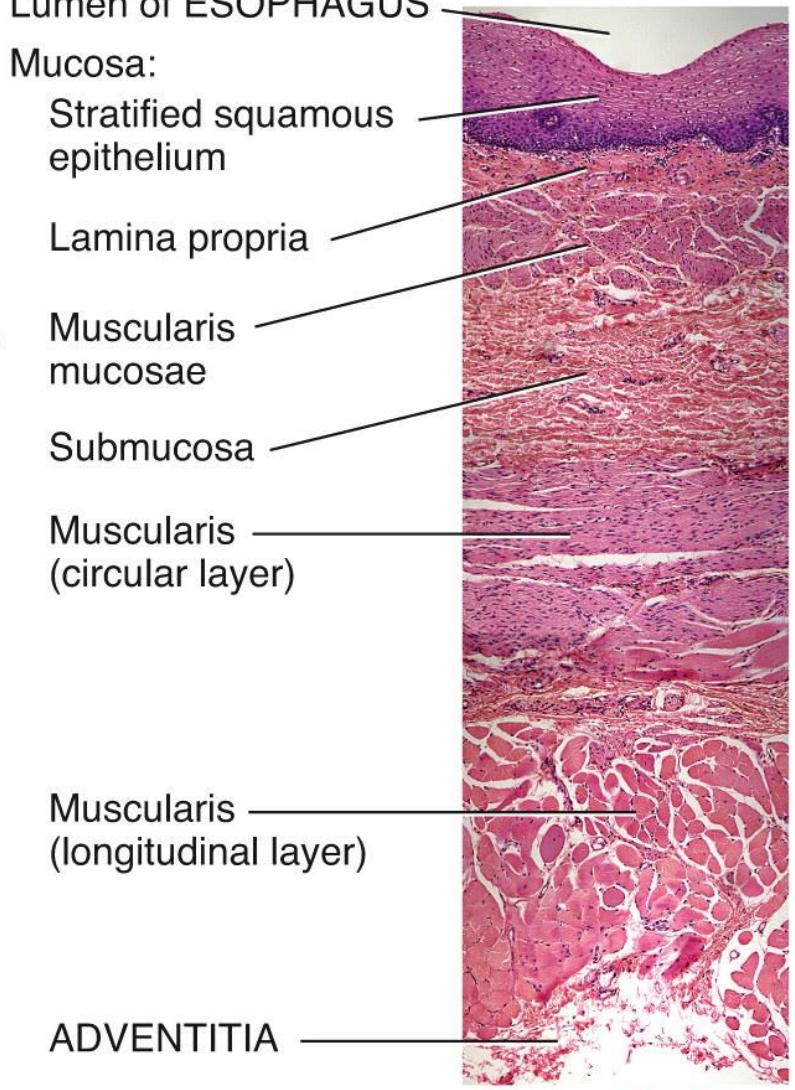
Esophagus





(b) Anterosuperior view of step dissection of esophagus

Dissection Shawn Miller, Photograph Mark Nielsen

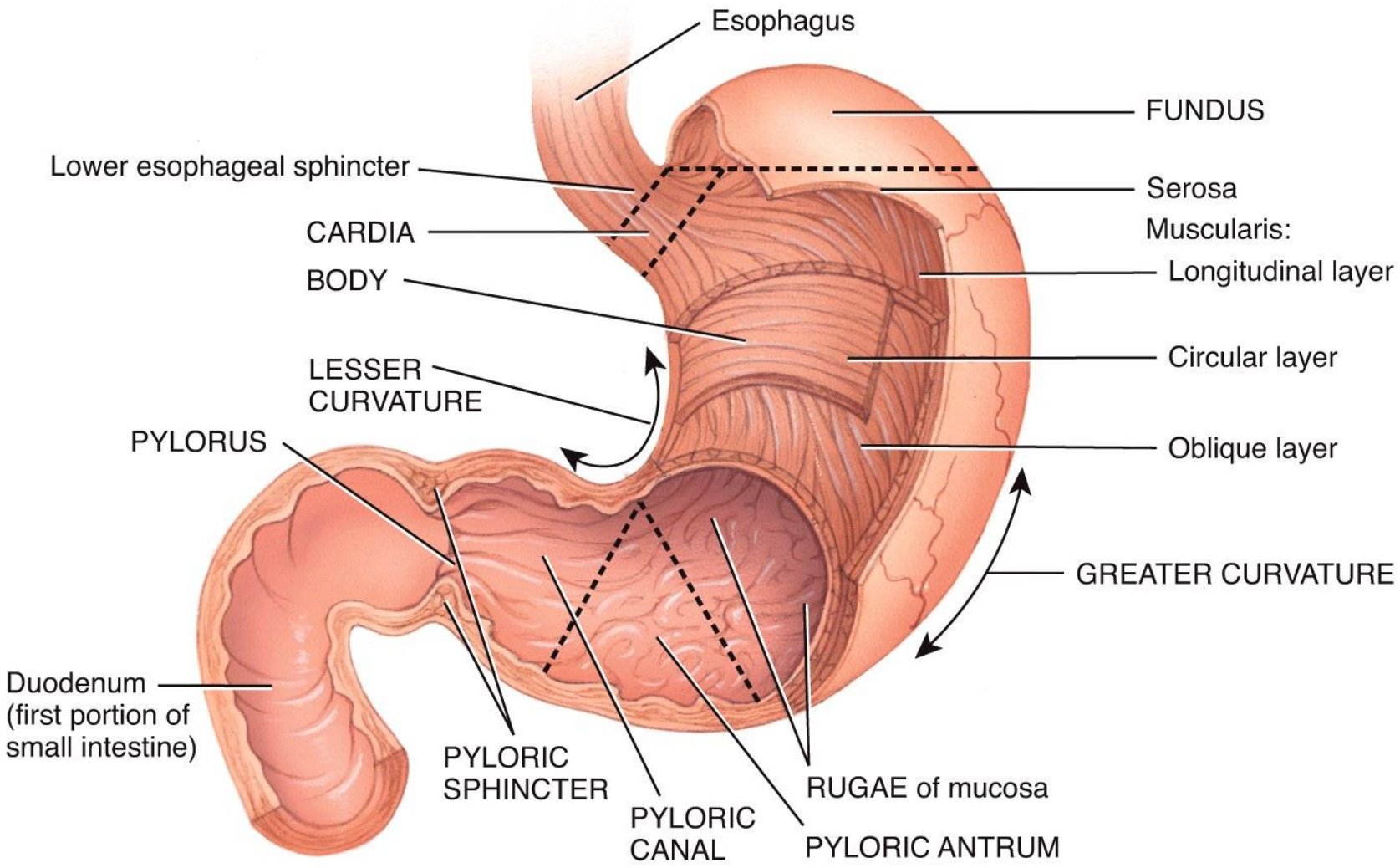


Wall of esophagus

Stomach

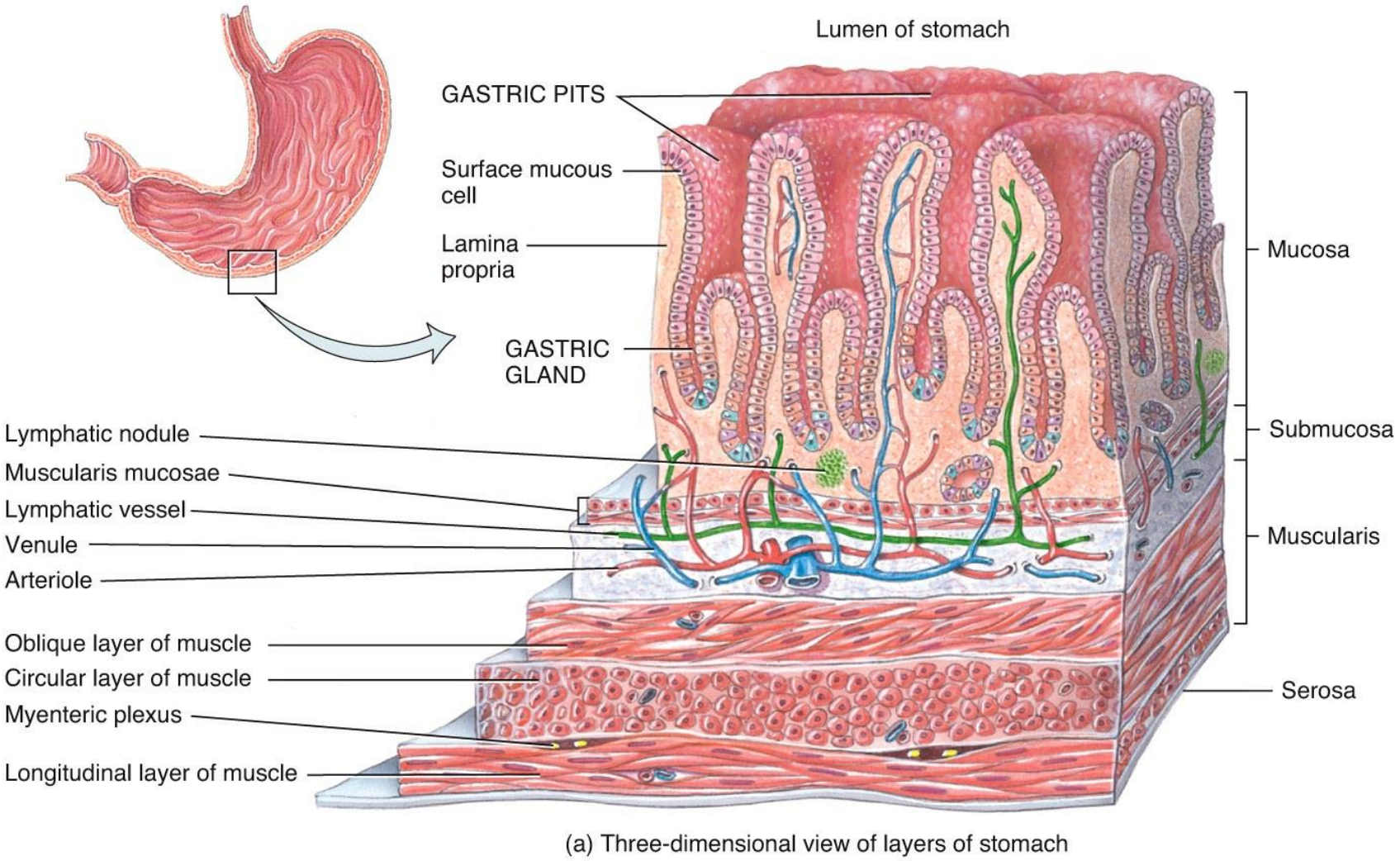
- Inferior to diaphragm, connects esophagus to duodenum
  - Major regions - cardia, fundus, body, and pylorus
  - Sphincters - lower esophageal and pyloric
  - Concave borders - lesser and greater curvatures
  - **Rugae -** internal folds of mucosa
- Histology - mucosa gastric pit cells secrete
  - Surface mucous cells and mucus neck cells - **mucus**
  - Parietal cells - **hydrochloric acid and intrinsic factor**
  - Chief cells - **pepsinogen and gastric lipase**
  - Enteroendocrine cells – **hormone gastrin**

Stomach



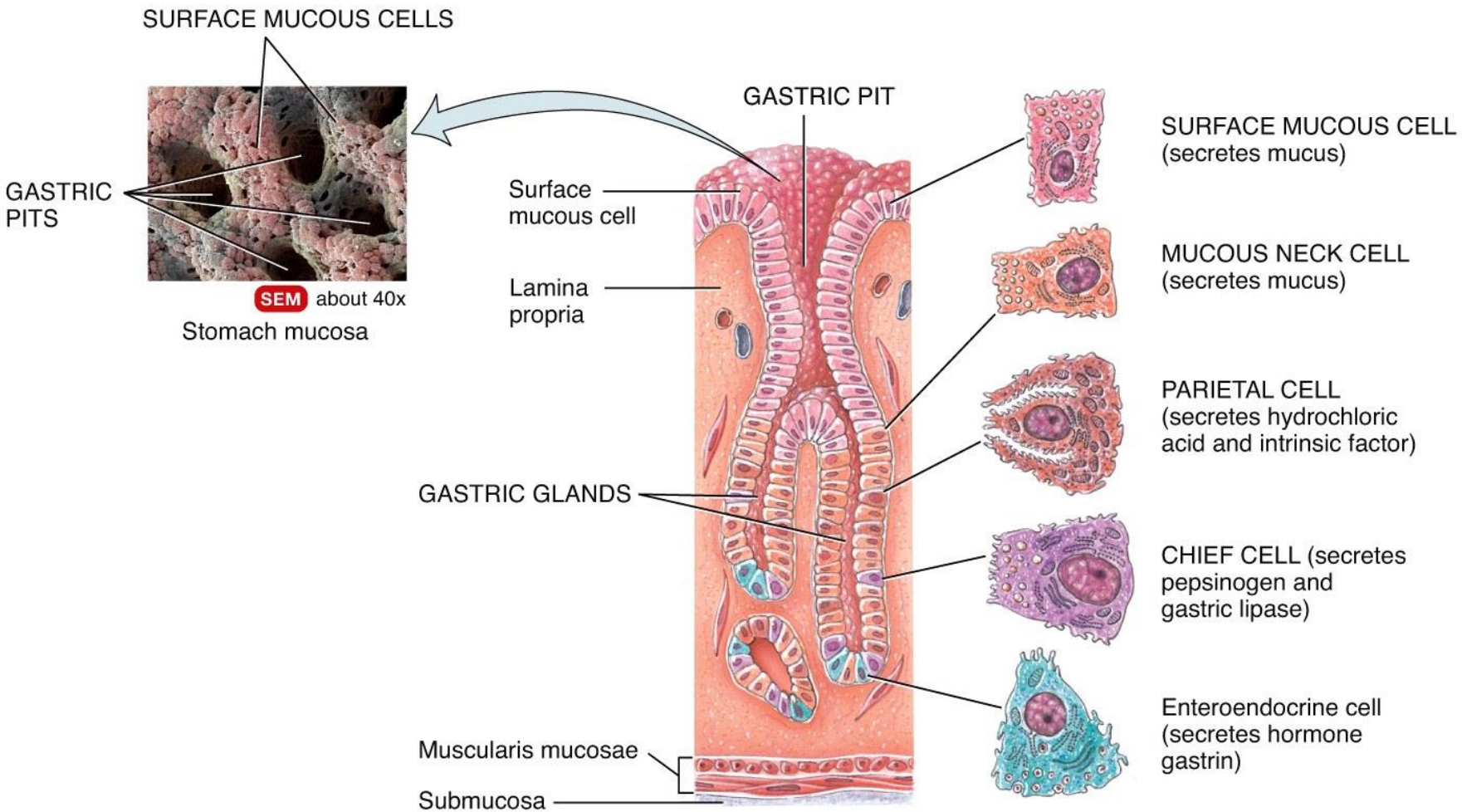
(a) Anterior view of external and internal anatomy

Stomach



(a) Three-dimensional view of layers of stomach

Stomach



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

Mechanical Digestion in Stomach

- Mixing waves
  - Facilitated by third, oblique smooth muscle layer
  - **Chyme** – soupy macerated food, mixed with gastric juice secretions
- **Gastrin**
  - Increases motility of stomach
  - Relaxes pyloric sphincter
- Gastric emptying
  - Small amount pushed through pyloric sphincter to duodenum
  - Carbohydrates first, then protein, then lipids

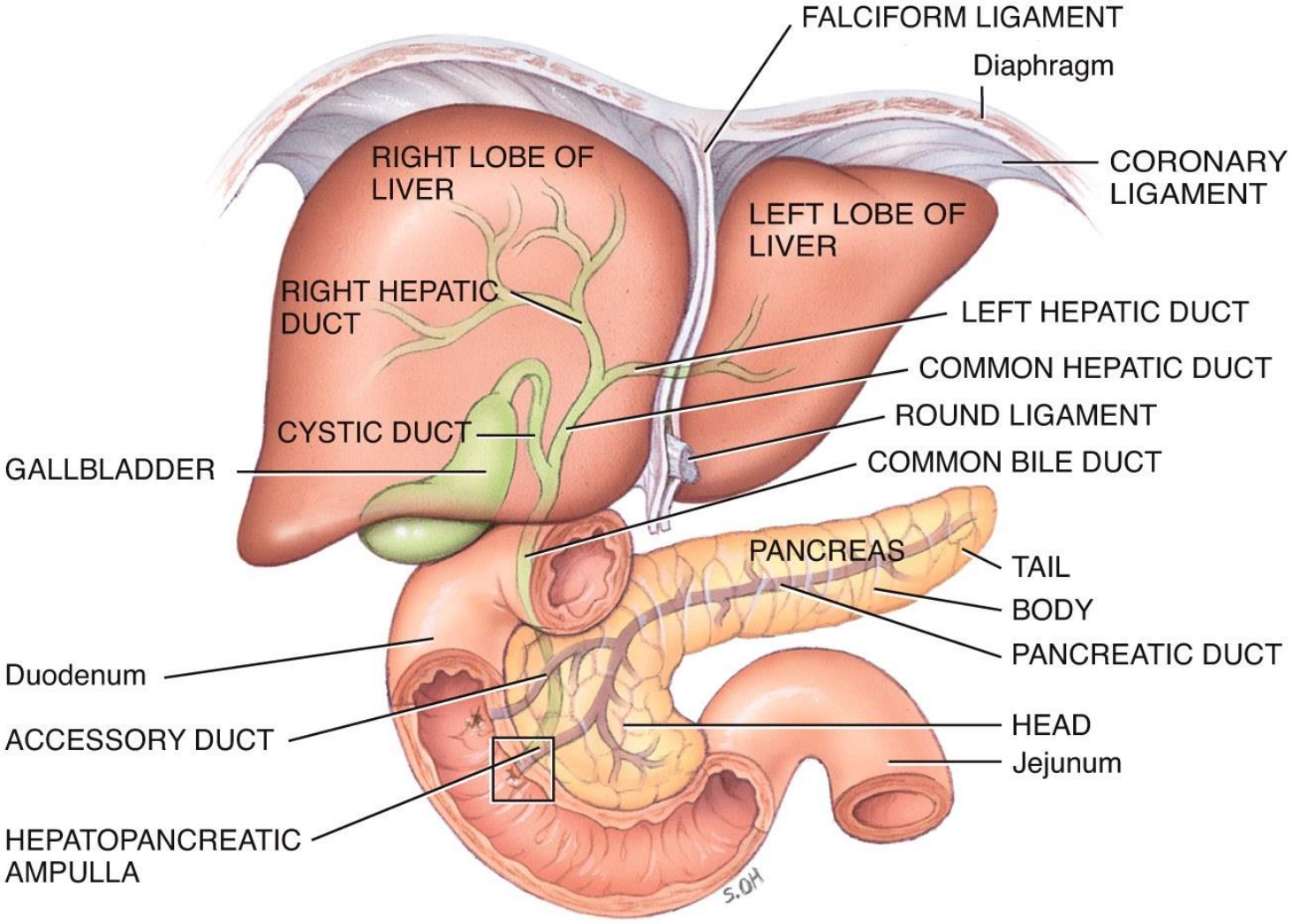
Chemical Digestion in Stomach

- Hydrogen and chloride secreted (parietal cell)
  - HCl kills microbes in food
  - Partially denatures protein
  - Regulated by acetylcholine, gastrin, and histamine
- **Pepsin** – protein enzyme (chief cell)
  - Secreted in inactive pepsinogen form
  - Activated by hydrochloric acid, epithelium protected by thick, alkaline mucus
- **Lipase** (gastric and lingual) – triglyceride enzyme
  - Activated by hydrochloric acid
- **Absorption by stomach is limited to water, certain ions, short-chain fatty acids, drugs, and alcohol**

Liver and Gallbladder

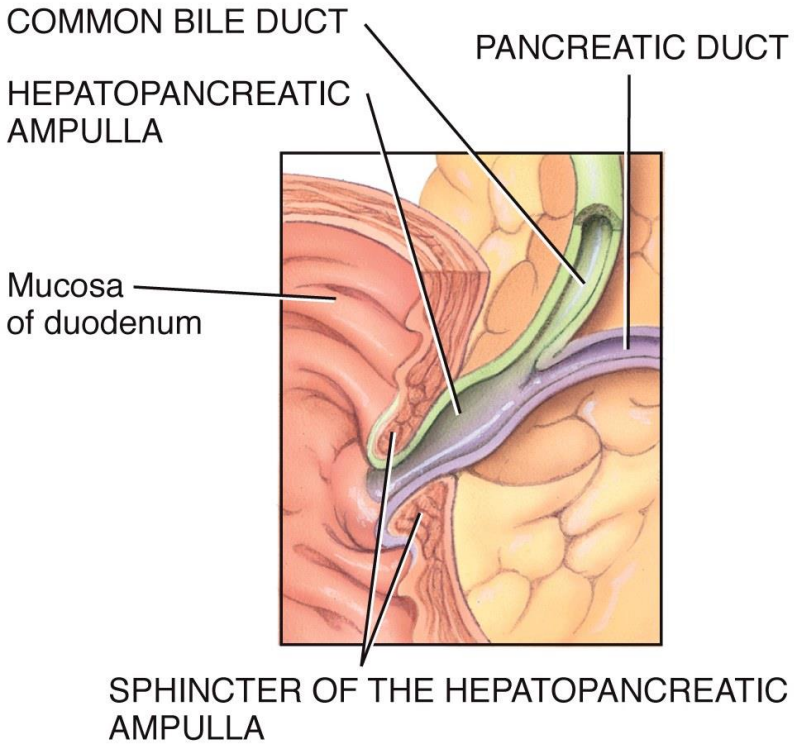
- Inferior to diaphragm, only one attached to anterior abdominal wall
  - Major regions - right and left lobe
- Gallbladder
  - Pear-shaped sac located in depression on posterior surface of liver, hanging from anterior inferior margin of liver
  - Cystic duct connects to common bile duct
  - Smooth muscle fiber in wall contracts to eject stored and concentrated bile

Liver and Gallbladder

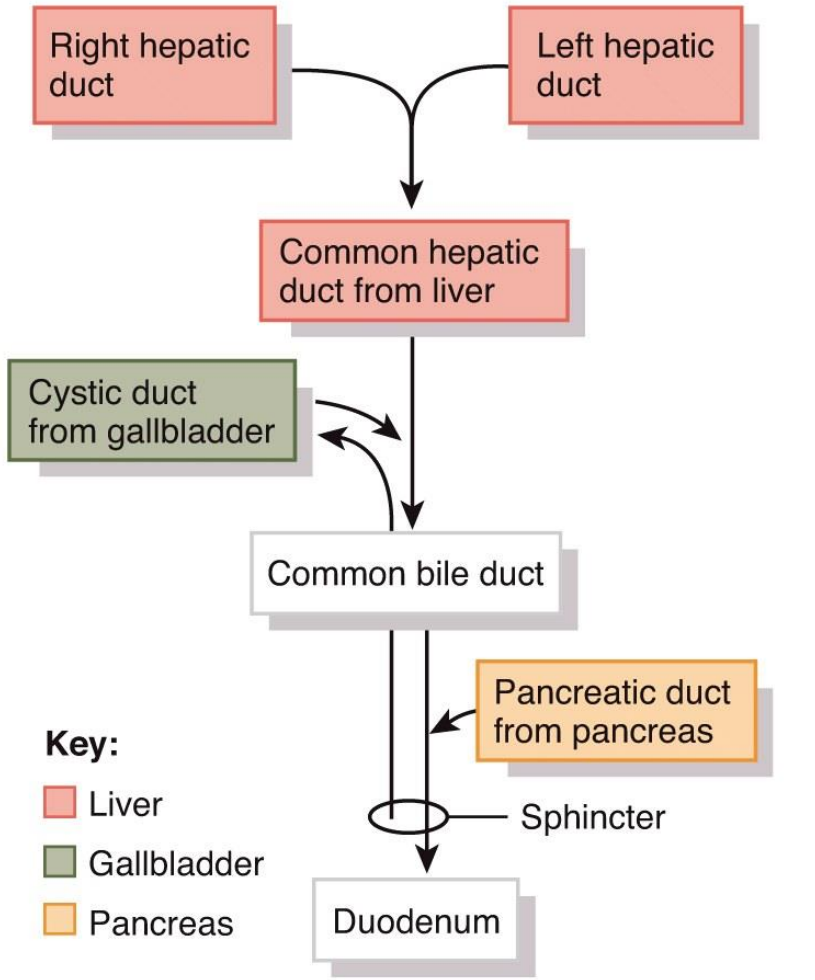


(a) Anterior view

Ducts from Liver, Gallbladder, and Pancreas



(b) Details of hepatopancreatic ampulla

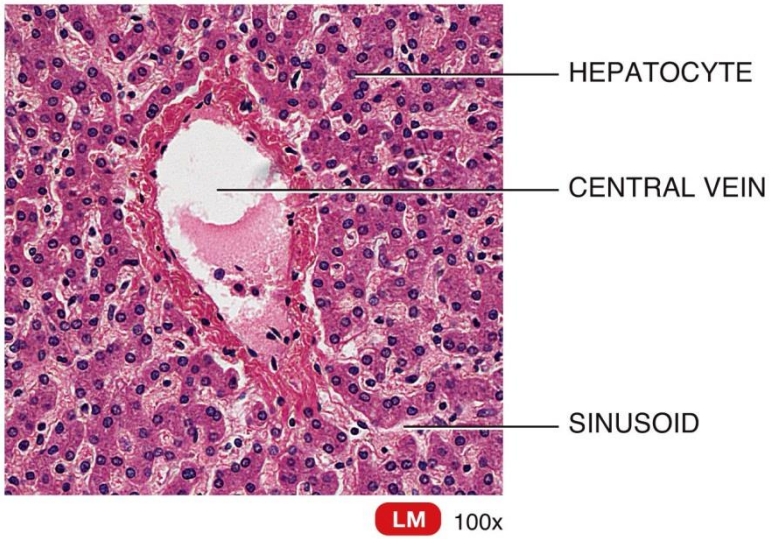


(c) Ducts carrying bile from liver and gallbladder and pancreatic juice from pancreas to duodenum

Liver Histology

- Hepatocytes produce **bile**
  - Interconnected rows radiating from central vein
  - Metabolic, secretory and endocrine functions
- Bile duct system
  - Canaliculi, bile ducts, right/left hepatic ducts, common hepatic duct, cystic duct, common bile duct
- Sinusoids
  - Permeable blood capillaries with phagocytic reticuloendothelial cells, converge into central vein
- Portal triads
  - Bile duct, branch of hepatic artery, and branch of hepatic portal vein

Liver Histology



(c) Photomicrograph

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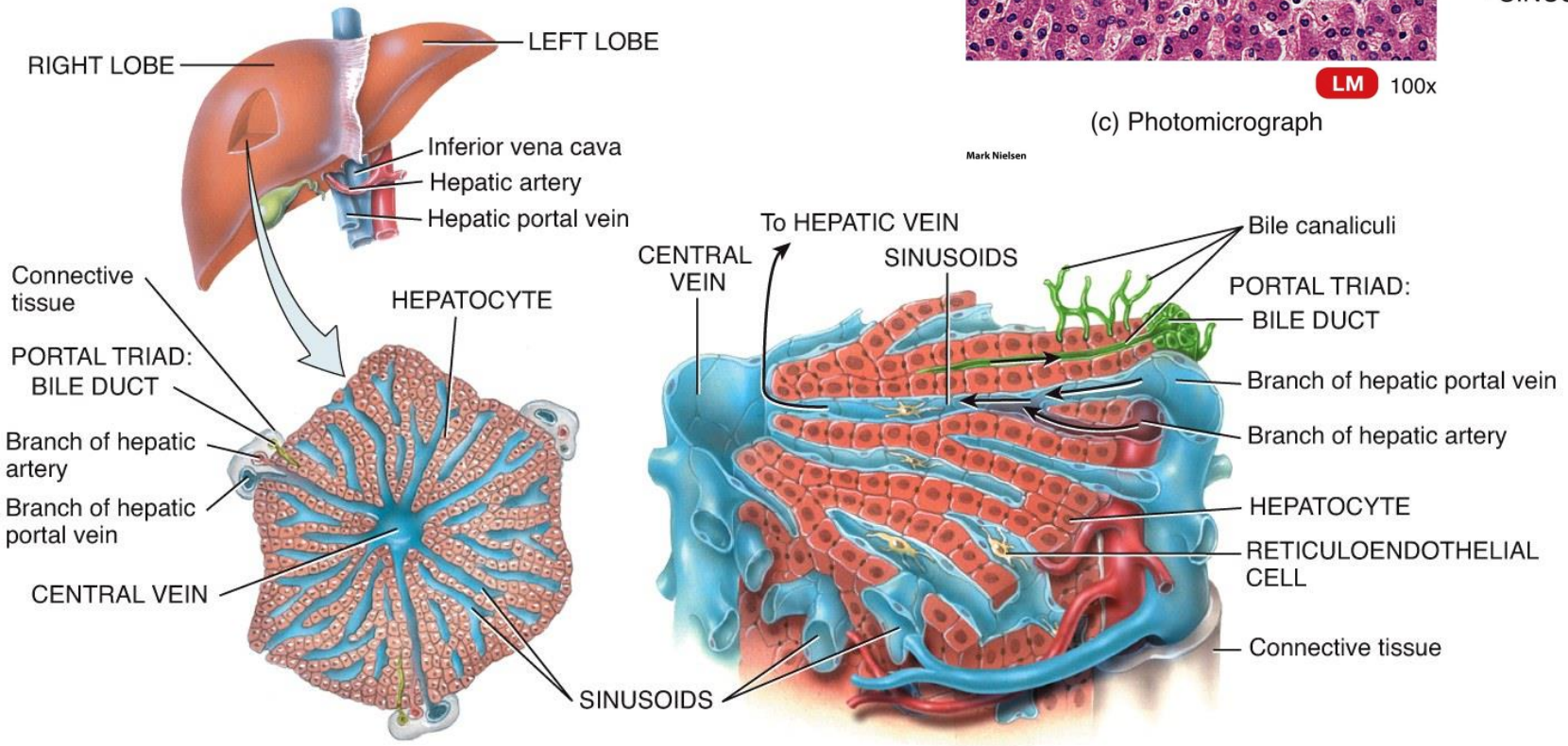


(a) Overview of histological components of liver

(b) Details of histological components of liver

Liver Blood Supply and Bile

- Two sources of blood to liver
  - Oxygen-rich blood in hepatic artery from abdominal aorta
  - Oxygen-poor blood, high in newly absorbed nutrients in hepatic portal vein from GI tract
- Blood mixes in sinusoids between hepatocytes
  - Uptake of oxygen, nutrients and toxins
  - Substances returned to blood, bile to bile canaliculi
  - Central vein, to hepatic vein and inferior vena cava
- Bile part excretory and part digestive secretion
  - Bile pigment bilirubin from hemoglobin destruction
  - Bile salts emulsify lipids into suspended globules

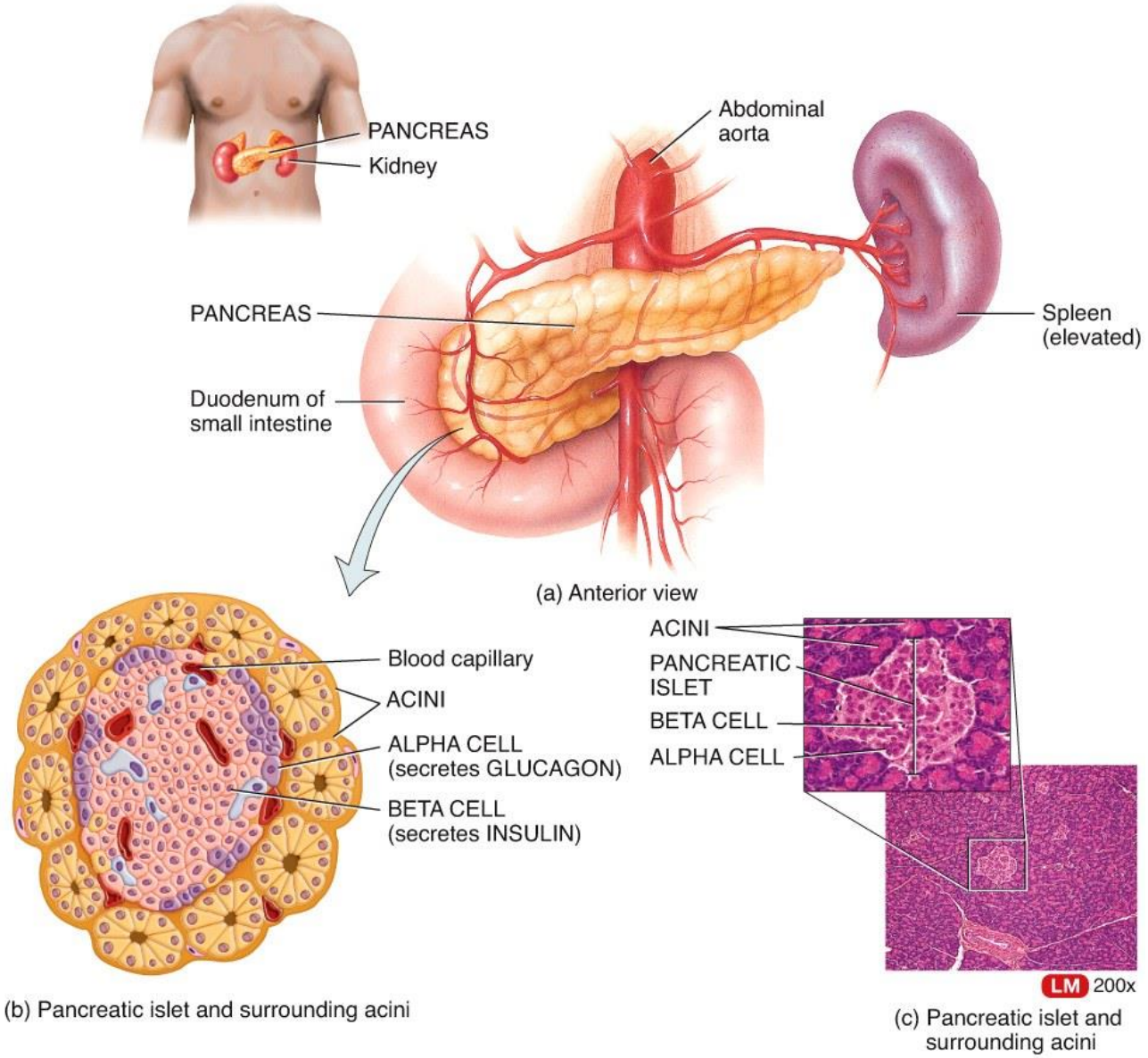
Liver Functions

- Production of bile for emulsification
- Carbohydrate metabolism (blood glucose level – glycogen storage)
- Lipid metabolism (store triglycerides, synthesize lipoproteins and cholesterol)
- Protein metabolism (for ATP production and synthesize blood proteins)
- Processing of drugs and hormones (detoxify alcohol and drugs, activate thyroid and steroid hormones)
- Excretion of bilirubin
- Storage (vitamins and minerals)
- Phagocytosis (reticuloendothelial cells)
- Activation of vitamin D (along with skin and kidneys)

Pancreas

- Retroperitoneal gland
  - Major regions - head, body, and tail
  - Sphincter of hepatopancreatic ampulla – shared entrance to duodenum controls passage of pancreatic juice through pancreatic duct and bile from liver and gallbladder through common bile duct
- Histology - exocrine and endocrine cells
  - **Acini cells** – secrete pancreatic juice in pancreatic and accessory duct to duodenum
  - **Pancreatic islet cells** – secrete hormones glucagon and insulin into blood

Pancreas



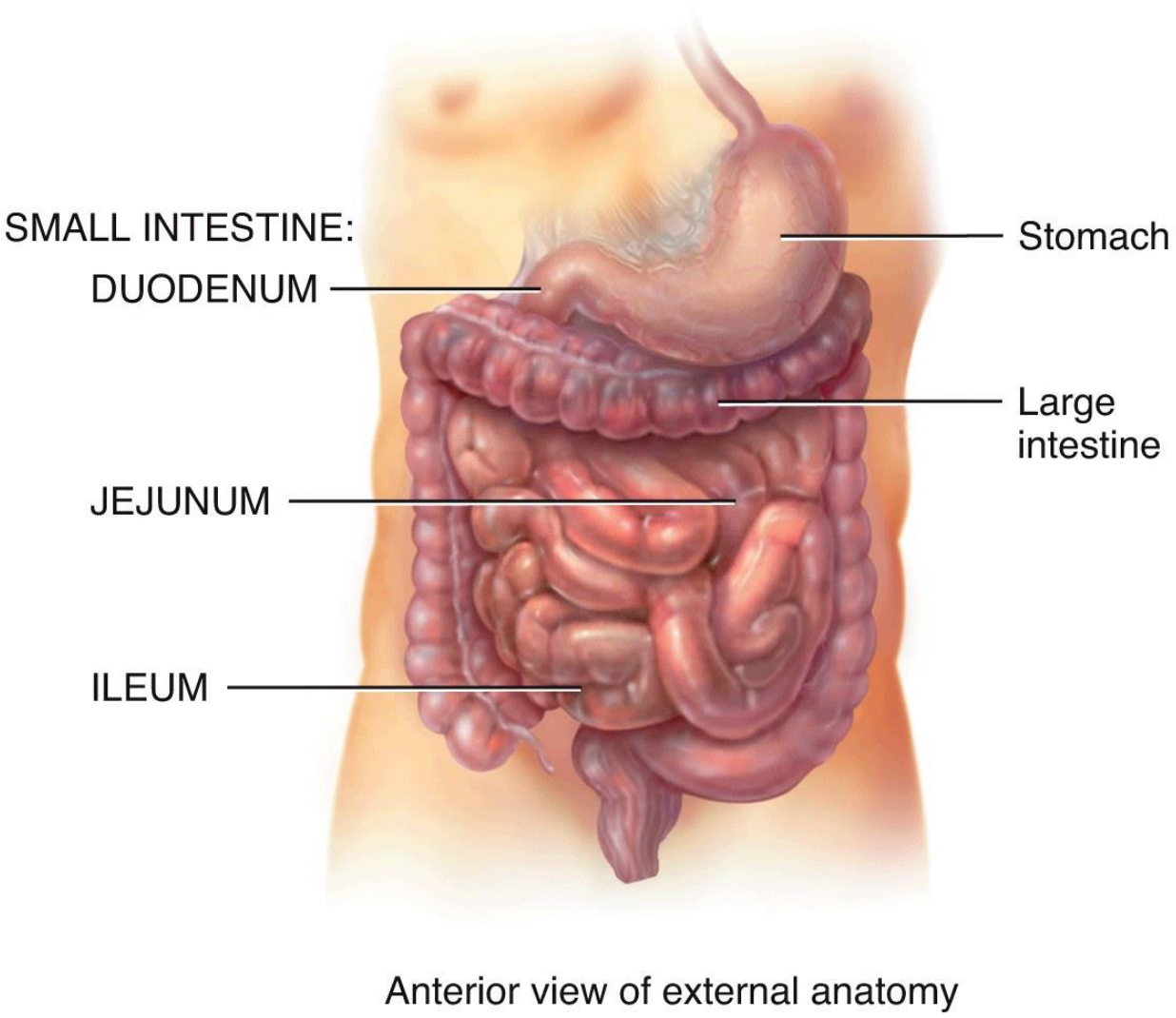
Chemical Digestion by Pancreatic Juice

- Pancreatic enzymes
  - Pancreatic **amylase** – digests starches
  - Protein enzymes
    - Secreted in inactive form-**zymogens**
    - Enterokinase enzyme activates trypsin, which can activate other protein enzymes
  - Pancreatic lipase – principal triglyceride digestion, not in acidic environment
  - Nucleic acid enzymes
- Sodium bicarbonate
  - Buffers acidic gastric juice in chyme
    - Stops action of pepsin
    - Creates proper pH for digestive enzymes in small intestine

Small Intestine

- Coils from pyloric sphincter at stomach to ileocecal sphincter at large intestine
  - Major regions
    - Duodenum – shortest, retroperitoneal
    - Jejunum
    - Ileum - longest
  - Plicae circulares - permanent folds of mucosa and submucosa increase surface area and force chyme to spiral as it passes through lumen
- Multiple structures to increase surface area for efficient digestion and absorption
  - Length, circular folds, finger-like villi, and microvilli

Small Intestine

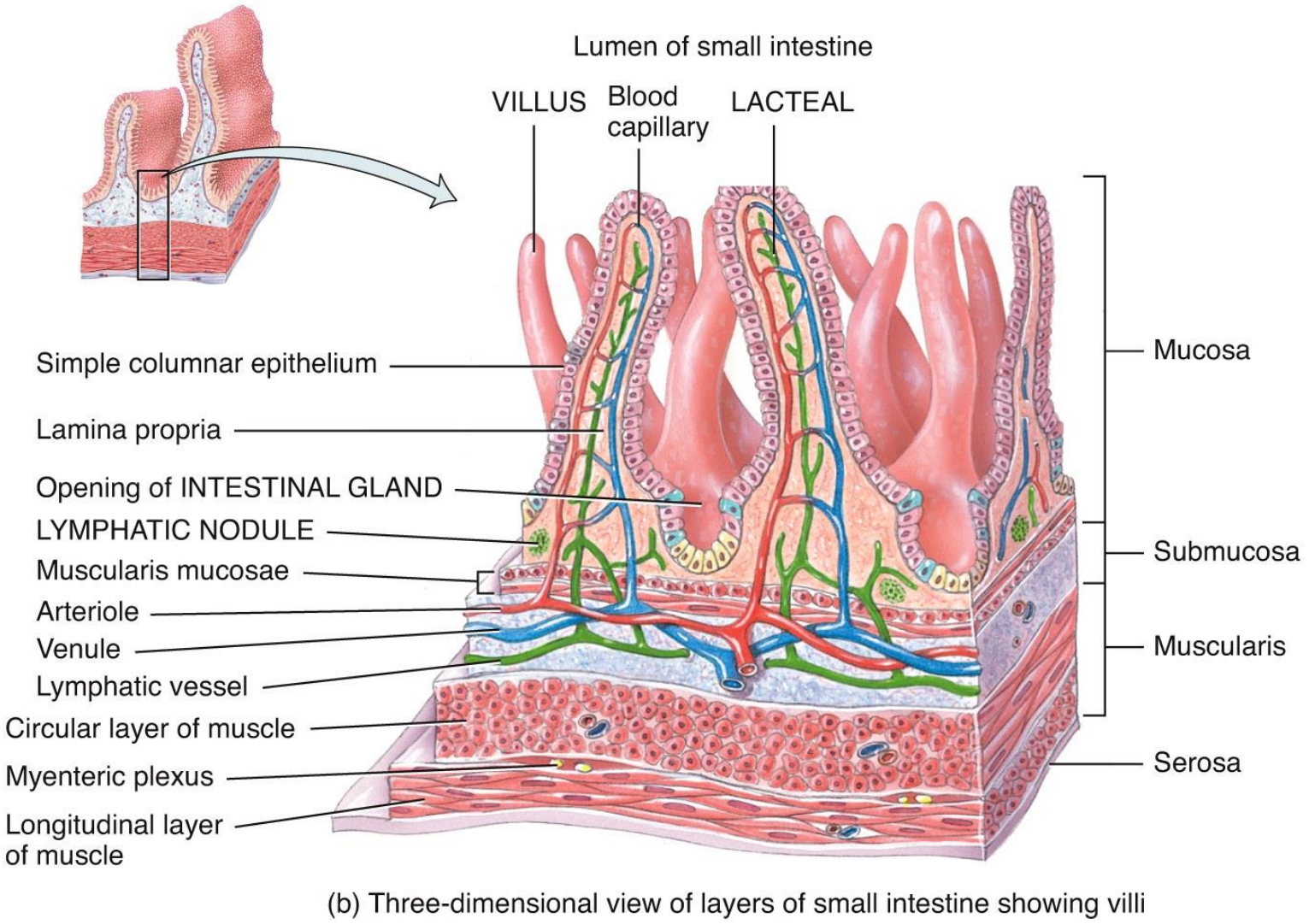


Anterior view of external anatomy

Small Intestine Histology

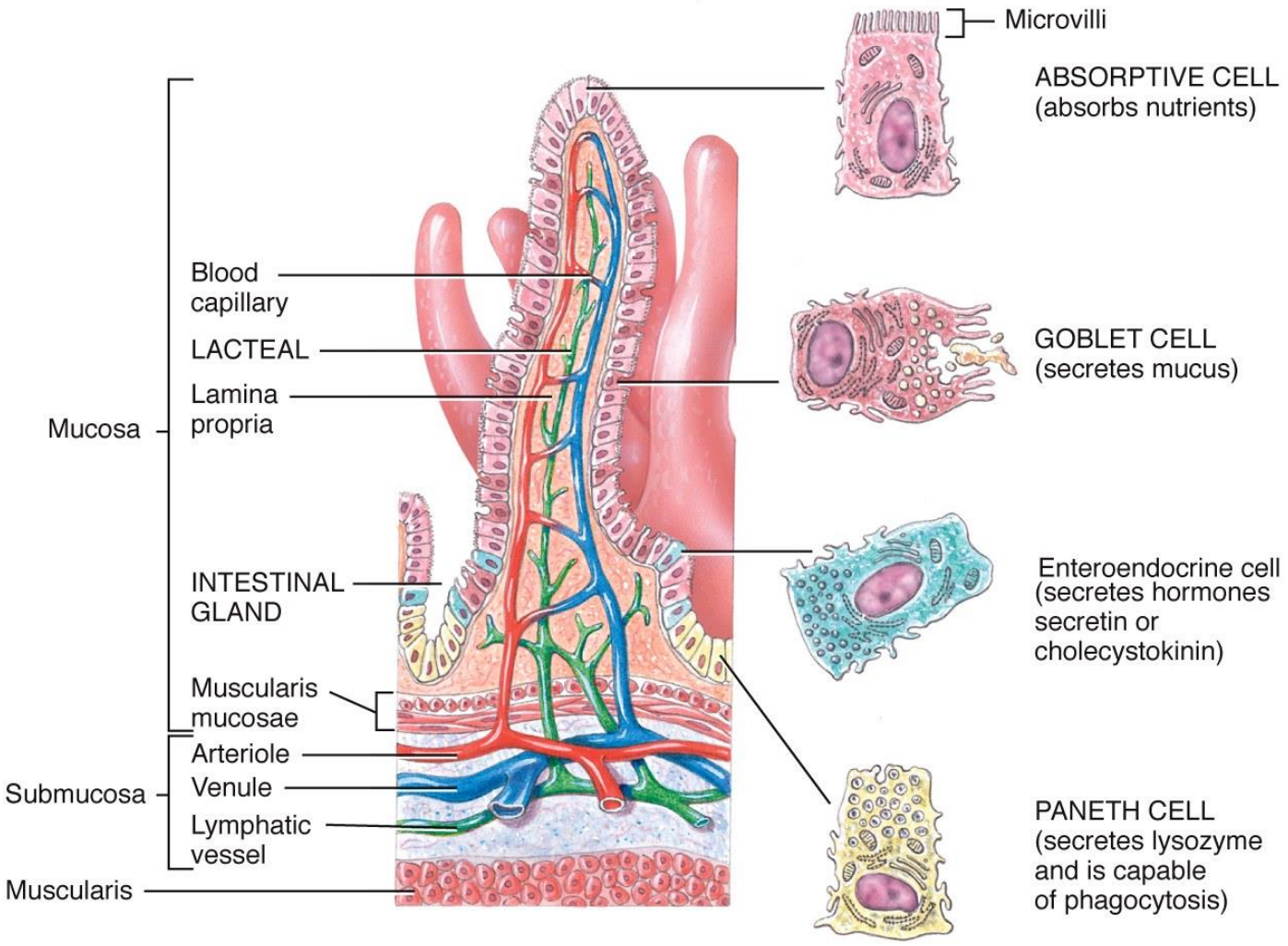
- Brush-border absorptive cells with microvilli
- Mucosal intestinal gland cells
  - Goblet cells (mucus) and Paneth cells (lysozyme)
- Lamina propria **MALT** and Peyer's patches
  - Defend against pathogens in food
- Submucosa duodenal glands
  - Alkaline mucus neutralizes gastric acid in chyme
- **Villi**
  - Fingerlike projection of mucosa and lamina propria
  - Contain blood capillary and lacteal lymphatic capillary

Small Intestine Histology



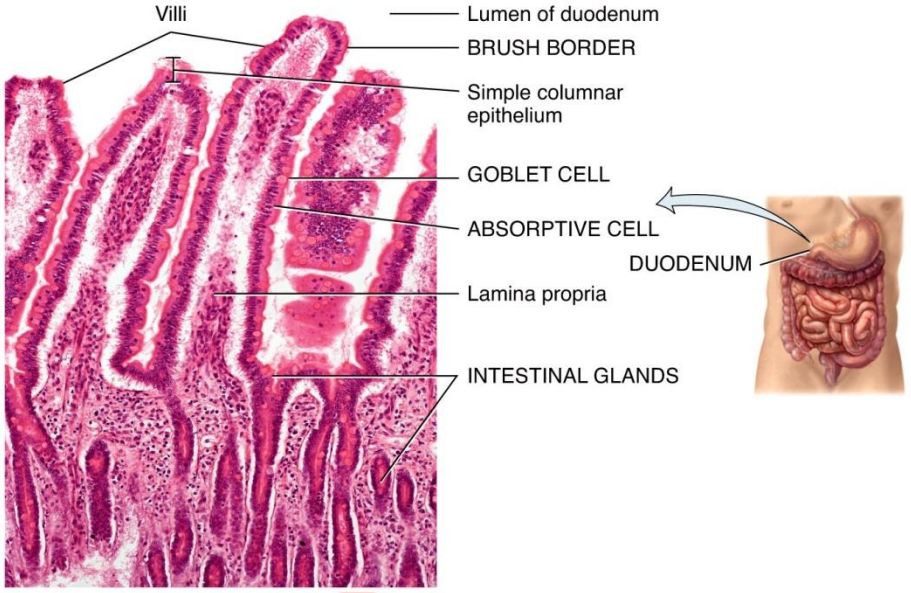
(b) Three-dimensional view of layers of small intestine showing villi

Small Intestine Histology

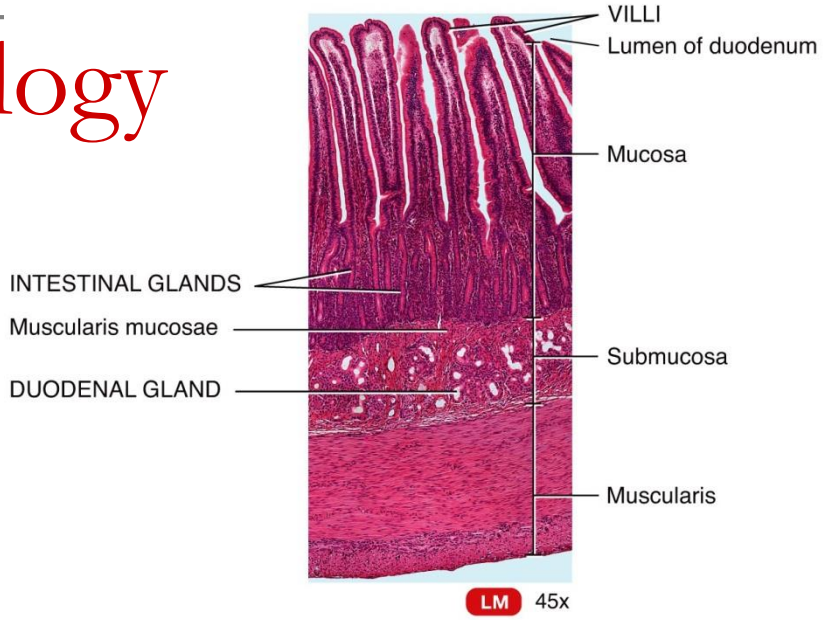


(c) Enlarged villus showing lacteal, capillaries, intestinal glands, and cell types

Small Intestine Histology



(b) Three villi from duodenum



(a) Wall of the duodenum

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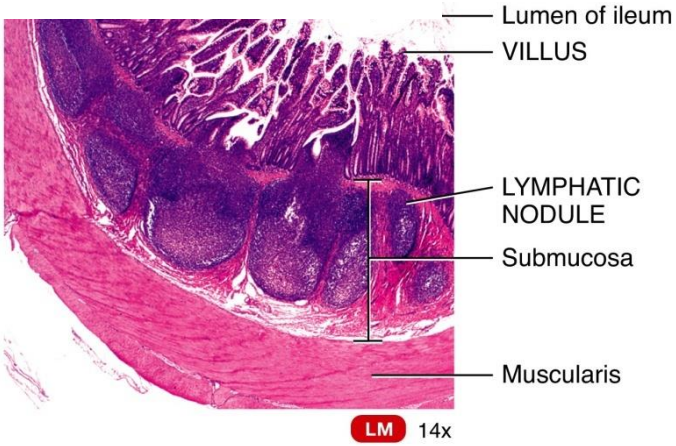
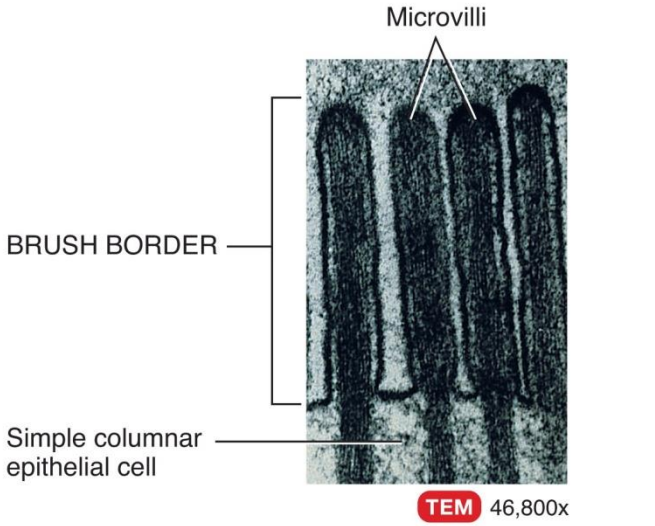


(c) Lymphatic nodules in ileum

Courtesy Michael Ross, University of Florida



(d) Several microvilli from duodenum

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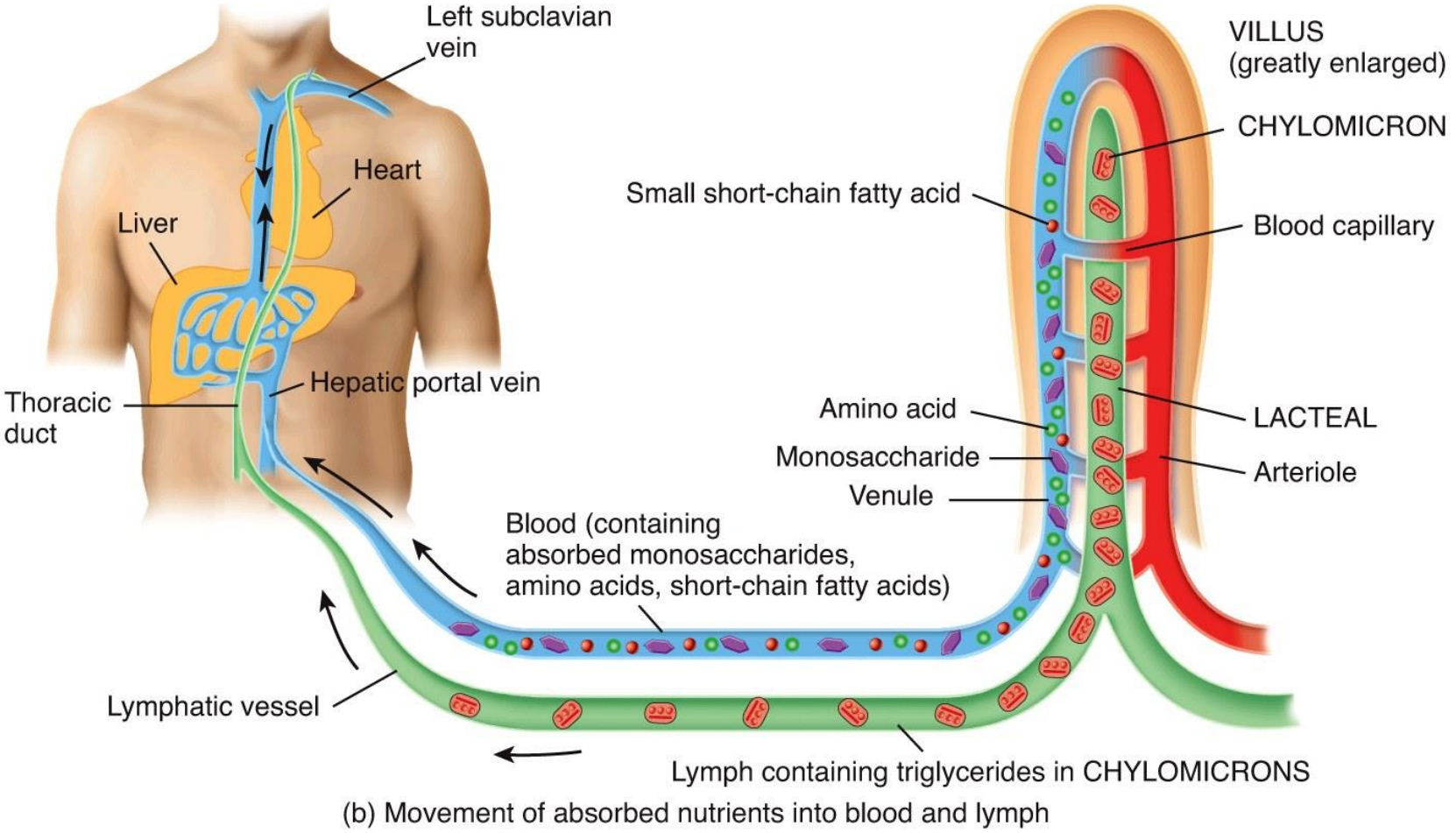
Mechanical Digestion in Small Intestine

- Segmentation
  - Localized mixing, slosh back and forth with circular muscle contractions
  - Mixes chyme with digestive juices in lumen and in contact with digestive enzymes in cell membrane of brush border cells
  - Brings food in contact with mucosa for absorption
- Peristalsis
  - Wave of coordinated smooth muscle contraction
  - Slowly pushes chyme forward along length of small intestine

Chemical Digestion in Small Intestine

- Intestinal enzymes mix with pancreatic enzymes in lumen; also brush border enzymes on microvilli
- Digestion of carbohydrates to monosaccharides
  - Pancreatic amylase and brush border sucrase, lactase, and maltase
- Digestion of proteins to amino acids
  - Pancreatic enzymes and brush border peptidase
- Digestion of lipids to fatty acid and glycerol
  - Amphipathic bile salts and pancreatic enzymes
- Digestion of nucleic acids to nucleotides
  - Pancreatic enzymes and brush border nucleosidases and phosphatases

Absorption in Small Intestine

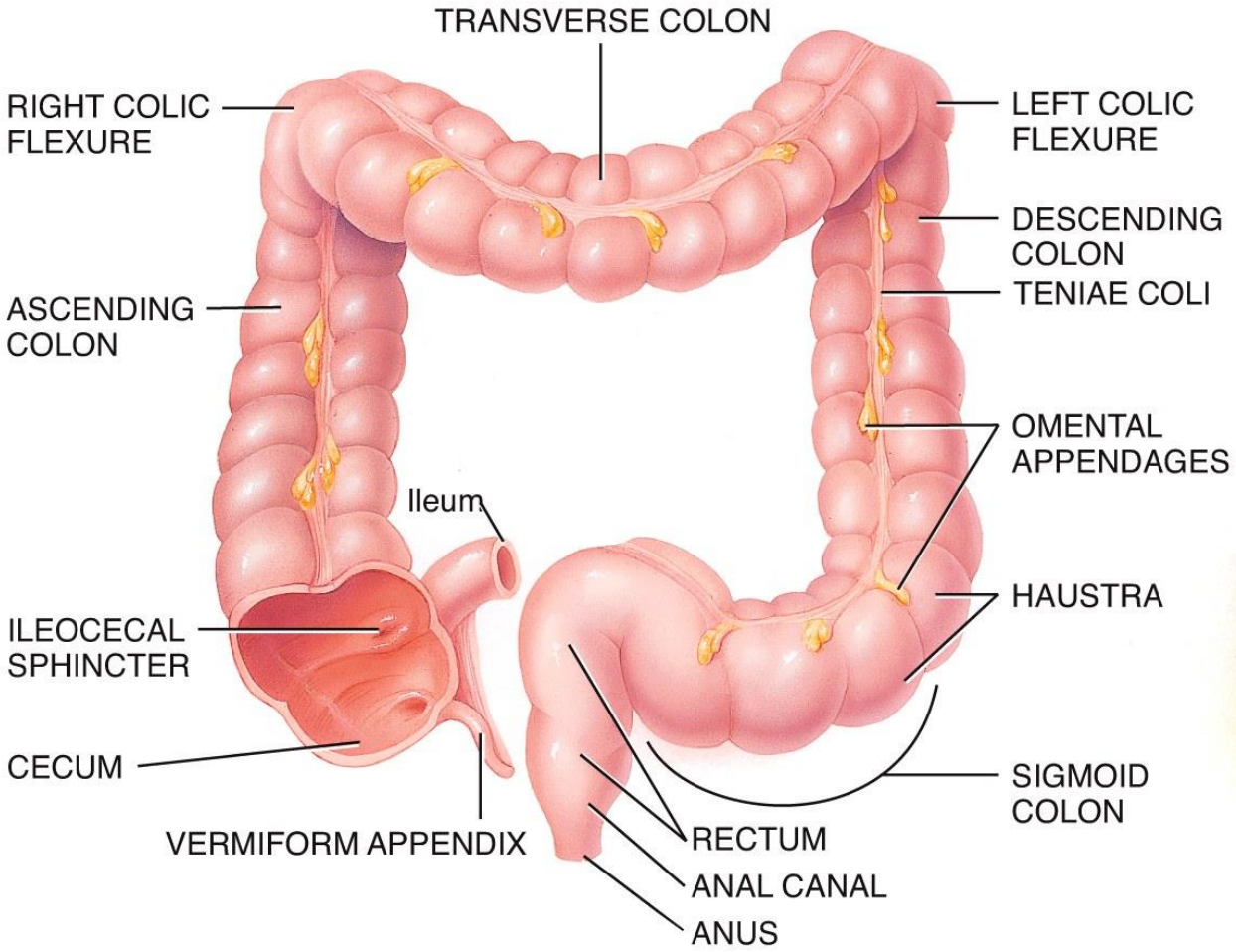


(b) Movement of absorbed nutrients into blood and lymph

Large Intestine

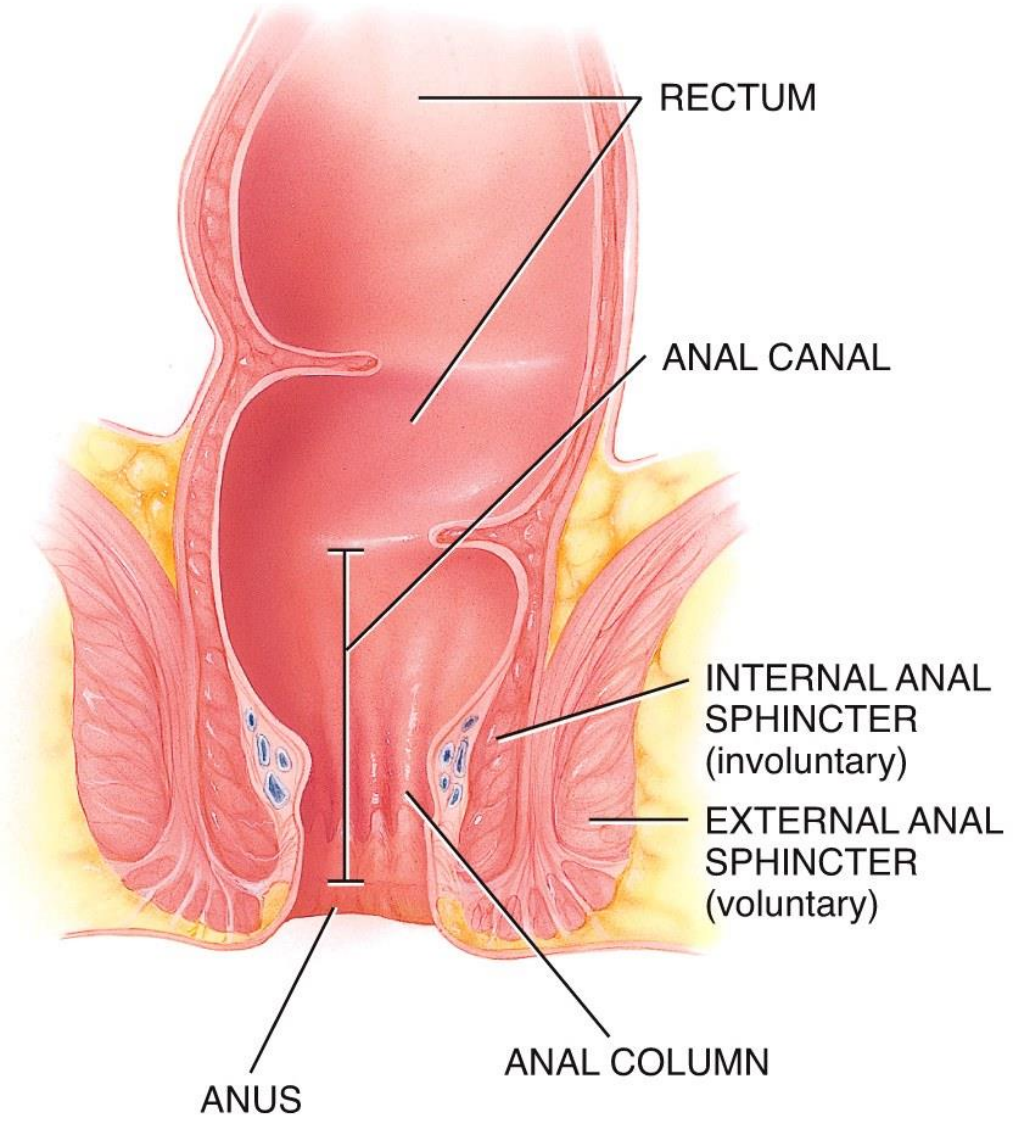
- Extends from small intestine to anus
  - Major regions
    - Cecum and vermiform appendix
    - Ascending, transverse, descending, and sigmoid colon
    - Rectum and anal canal
  - Sphincters
    - Ileocecal – connection to small intestine
    - Internal anal – involuntary, smooth muscle
    - External anal – voluntary, skeletal muscle

Large Intestine



(a) Anterior view of large intestine showing major regions

Large Intestine

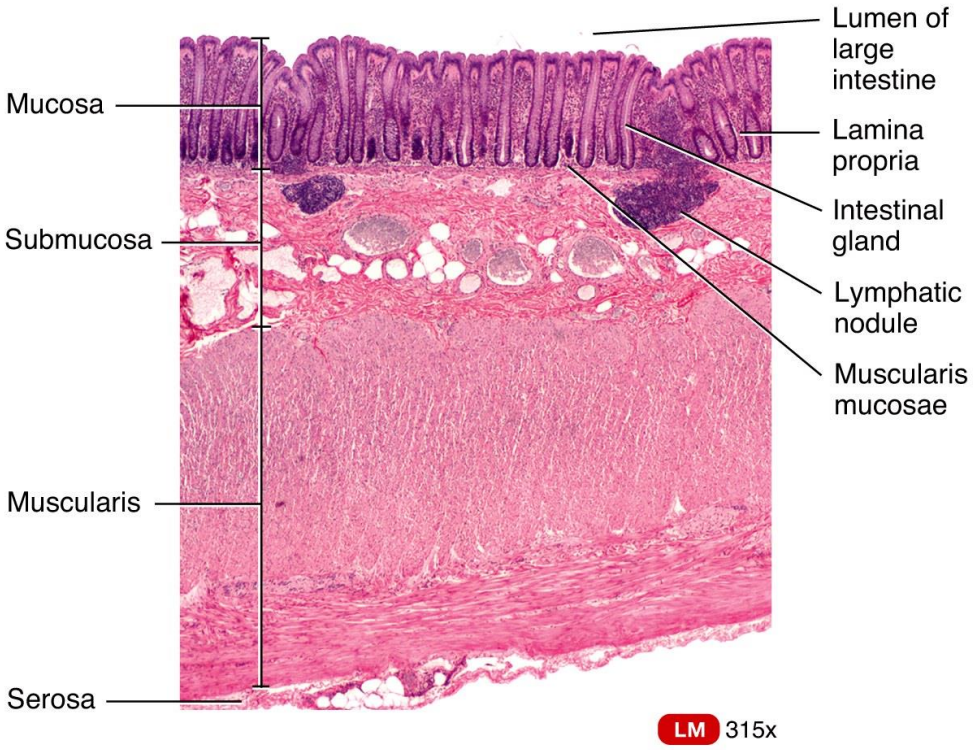


(b) Frontal section of anal canal

Large Intestine Histology

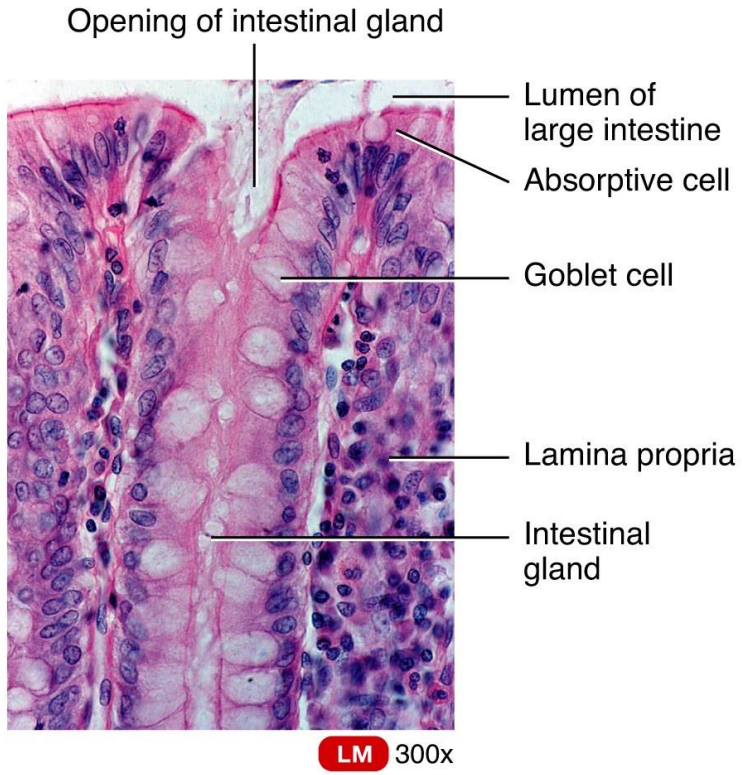
- Mucosal intestinal gland cells
  - Goblet cells (mucus) and absorptive cells with microvilli (mainly water)
- Lamina propria and submucosa lymphatic nodules
  - Defend against pathogens in food
- Muscularis
  - Thickened longitudinal muscle forms teniae coli bands, forming haustral pouches
- Omental appendages
  - Fat filled pouches of visceral peritoneum

Large Intestine Histology



(c) Portion of wall of large intestine

Courtesy Michael Ross, University of Florida



(d) Details of mucosa of large intestine

Courtesy Michael Ross, University of Florida

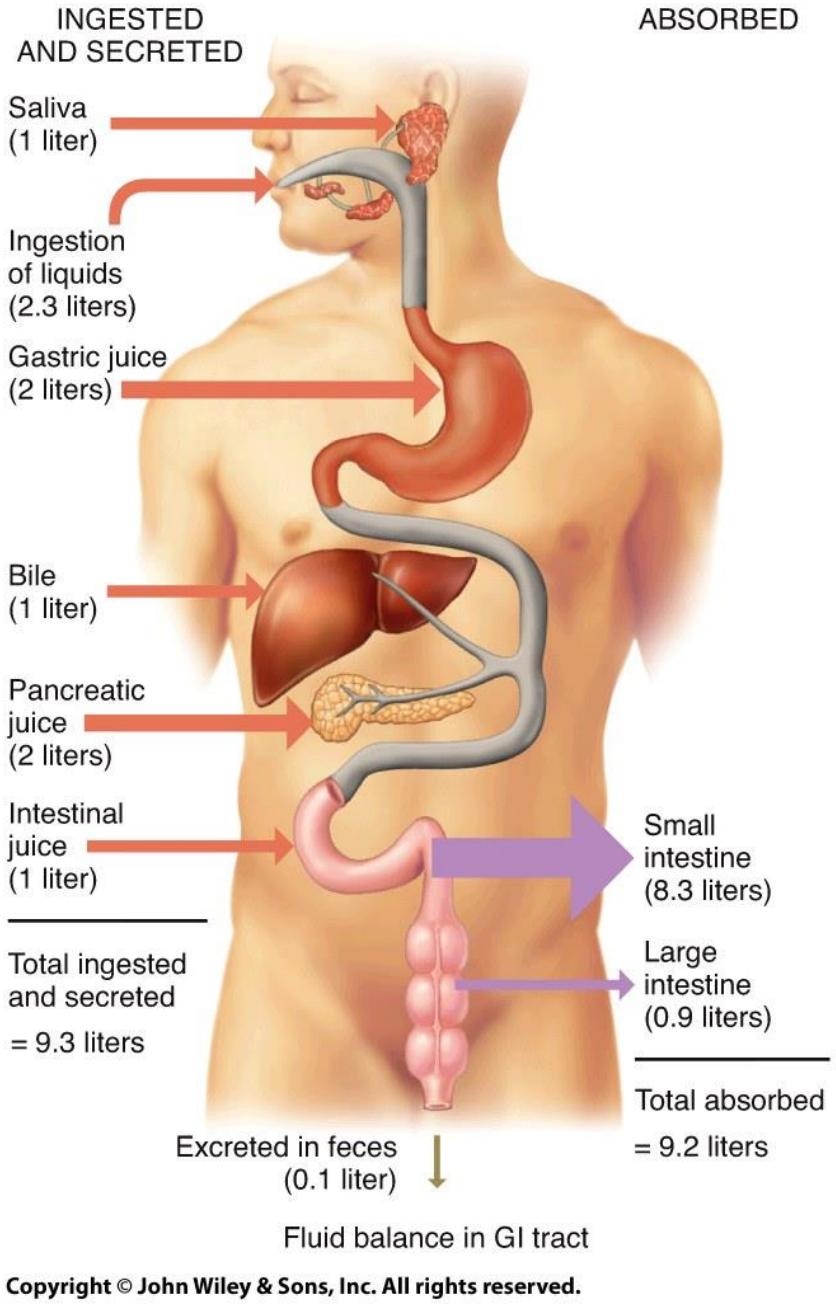
Mechanical Digestion in Large Intestine

- Gastroileal reflex
  - Intensified peristalsis in ileum, immediately after meal, and gastrin hormone relaxes ileocecal sphincter
- Haustral churning
  - Haustra alternately relax and distend, then contract and squeeze contents into next haustra
- Mass peristalsis – gastrocolic reflex
  - Quickly from middle of transverse colon into rectum, several times a day, or during or immediately after meal

Chemical Digestion and Absorption in Large Intestine

- Mucus is secreted, but no enzymes secreted
- Bacteria inhabiting the lumen process chyme
  - Ferment remaining carbohydrates, releasing gases
  - Digest remaining proteins and decompose bilirubin
  - Also produce several vitamins needed for normal metabolism, including vitamin K and some B vitamins
- **Absorption includes water, Na^+, Cl^-, vitamins**
- **Feces** is semi-solid chyme for elimination
  - Includes inorganic salts, sloughed-off epithelial cells, bacteria and metabolic by-products, unabsorbed digested material, and indigestible parts of food

Water Absorption in GI Tract and Fluid Balance



Defecation Reflex

- Stimulated by distention of rectal wall when mass peristalsis pushes feces into rectum
- Parasympathetic stimulation opens the internal anal sphincter
- Voluntary relaxation of external anal sphincter allows feces to be expelled
- Affected by factors such as diet, health, and stress
  - Diarrhea – increase in frequency, volume and fluid content caused by increased motility and decreased absorption
  - Constipation – infrequent or difficult defecation caused by decreased motility and increased absorption of water because of retention

Lesson 3: Anatomy of the Excretory System

Objective:

Describe the anatomy and function of the urinary tract and kidneys

Introduction

- Urinary System works with the Respiratory System to rid the body of non-useful metabolic byproducts
- Kidneys help maintain homeostasis by:
  - Filtering blood plasma
  - Returning most water and useful solutes to bloodstream
  - Selectively eliminating unneeded substances
- Resulting urine is stored and transported for excretion by other organs of urinary system

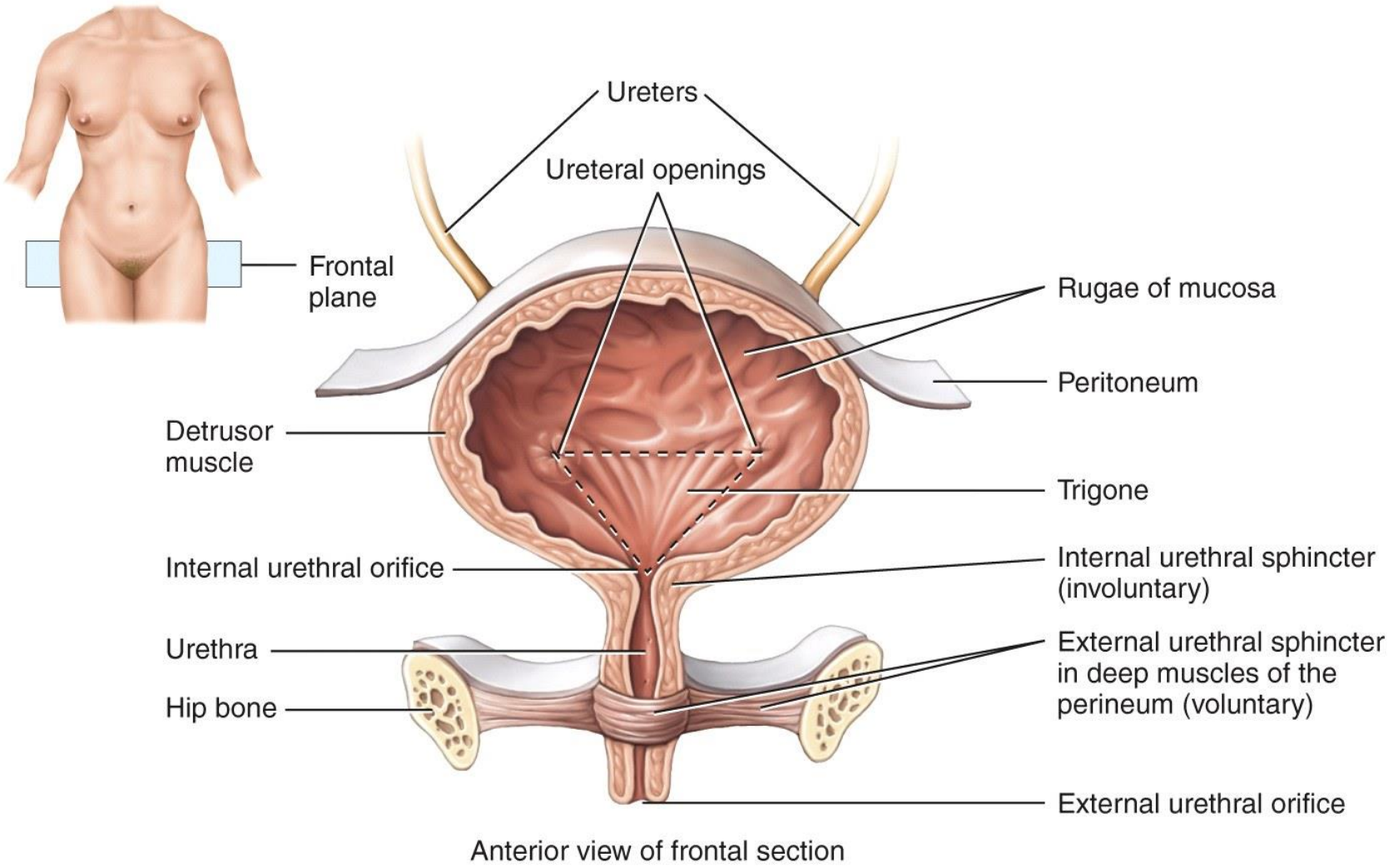
Urine Transport: Ureters

- Transport urine from renal pelvis to urinary bladder
  - Retroperitoneal
  - **Urine flow by peristalsis, hydrostatic pressure and gravity**
  - Physiological valve prevents backflow by compression of opening as bladder fills with urine
- 3 layers of ureter wall
  - Inner mucosa of transitional epithelia - stretch and mucus protection
  - Muscularis of longitudinal and circular smooth muscle
  - Superficial adventitia of areolar connective tissue

Urine Storage: Urinary Bladder

- Hollow, distensible muscular organ in pelvic cavity, posterior to pubic symphysis, inferior to peritoneum
  - Two ureteral openings posterior
  - Internal urethral orifice anterior
- 3 layers of bladder wall
  - Inner mucosa of transitional epithelia - rugae permit expansion
  - Detrusor muscle – 3 layers of smooth muscle
  - Superficial adventitia or peritoneum
- Sphincters control emptying of bladder
  - Internal urethral sphincter - smooth muscle, involuntary
  - External urethral sphincter - skeletal muscle, voluntary

Urinary Bladder



Anterior view of frontal section

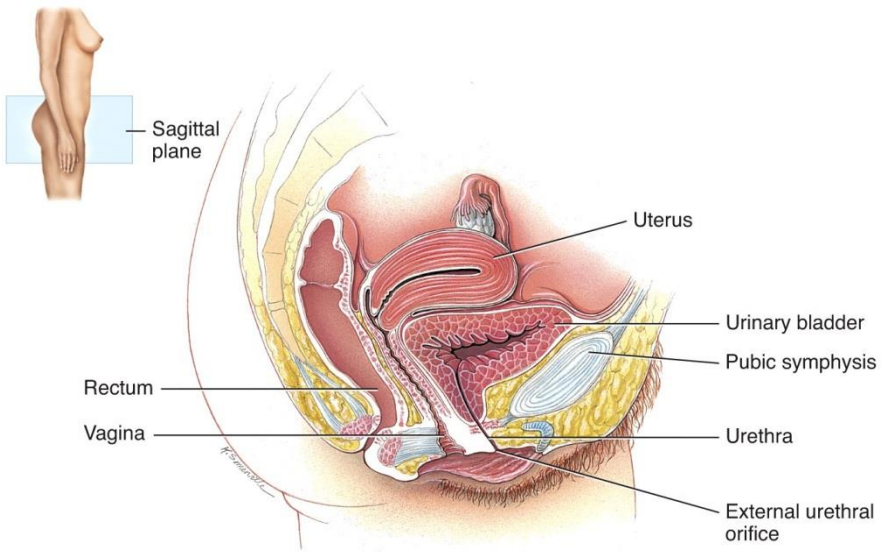
Micturition Reflex

- Discharge of urine from urinary bladder into urethra
- Stretch receptors stimulate sacral spinal reflex arc
  - Stimulates Parasympathetic impulses
    - Contraction of detrusor muscle
    - Relaxation of internal urethral sphincter muscle
  - Inhibits Somatic motor neuron impulses
    - Relaxation of external urethral sphincter muscle
- Can initiate or delay voluntarily through learned control by cerebral cortex

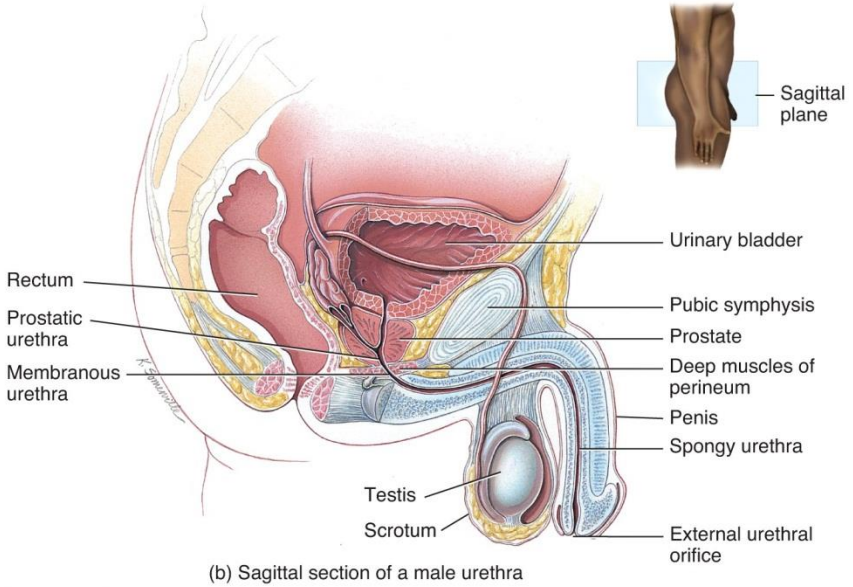
Urethra

- Leads from bladder to exterior of body for discharge of urine the body
- Females – short with exterior opening between clitoris and vaginal opening
- Males
  - Also discharges semen with exterior opening through the penis
  - Subdivided into 3 regions
    - Prostatic urethra
    - Membranous urethra
    - Spongy urethra

Male and Female Urethras

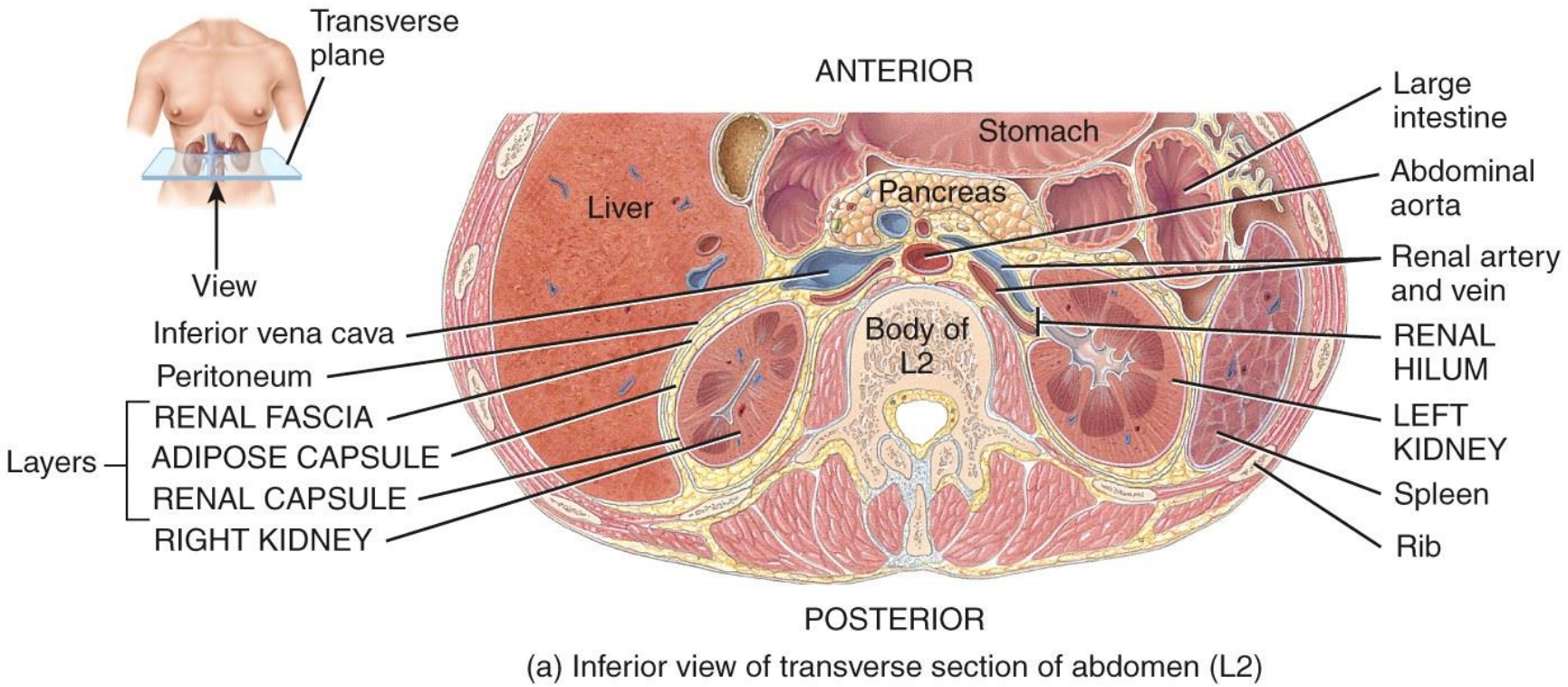


(a) Sagittal section of a female urethra



(b) Sagittal section of a male urethra

Location and External Anatomy of Kidney



(a) Inferior view of transverse section of abdomen (L2)

Kidney Functions

- Regulates various properties of the blood
  - Ionic composition
  - pH
  - Volume
  - Pressure
  - Glucose level
- Produces hormones
  - Calcitriol
  - Erythropoietin
- Excretes waste and foreign substances

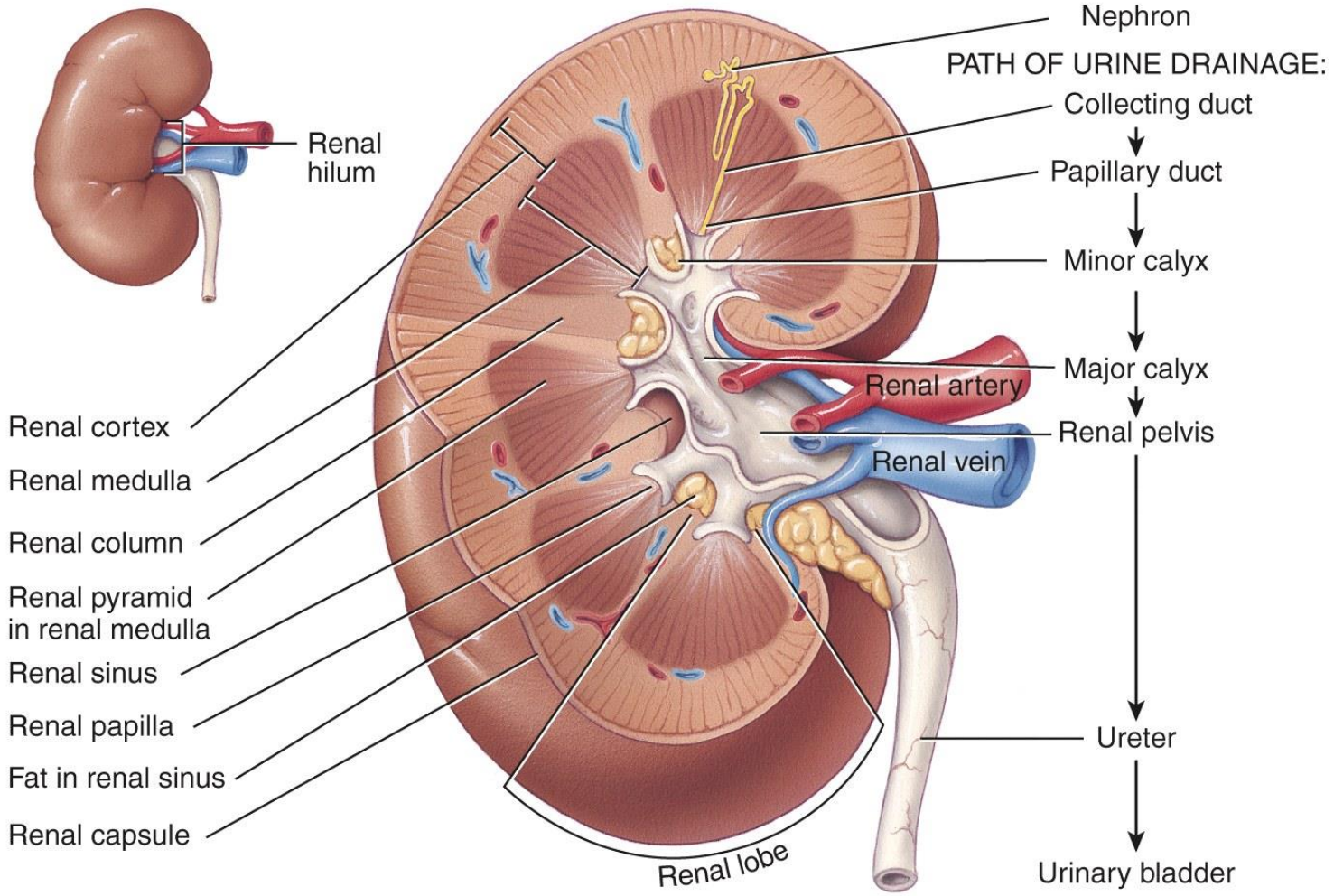
Location and External Anatomy of Kidney

- Paired, retroperitoneal organs
- Renal hilum
  - Indentation where ureter exits and nerves, blood and lymphatic vessels enter and exit
- 3 layers of connective tissue
  - Renal capsule – deep
    - Maintains shape and forms barrier
  - Adipose capsule – middle
    - Cushions and supports
  - Renal fascia – superficial
    - Anchors to abdominal wall

Internal Anatomy of the Kidney

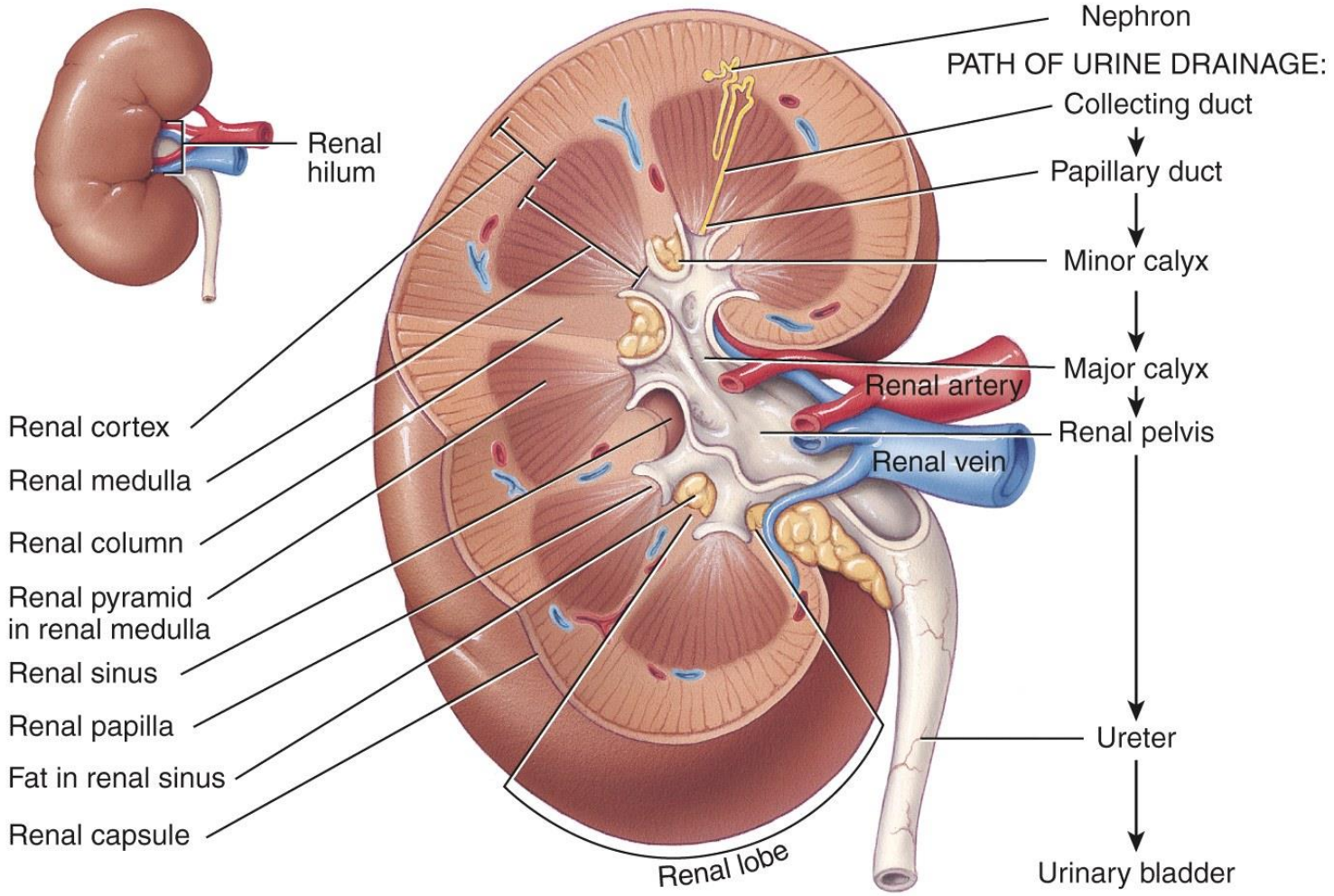
- Renal cortex
- Renal medulla
  - Renal pyramids
    - Papillary duct of collecting duct
  - Renal columns
    - Renal cortex tissue extending between pyramids
- Renal sinus
  - Minor calyx
  - Major calyx
  - Renal pelvix
  - Branches of renal blood vessels and nerves
  - Adipose

Internal Anatomy of the Kidney



(a) Frontal section of right kidney

Path of Urine Drainage

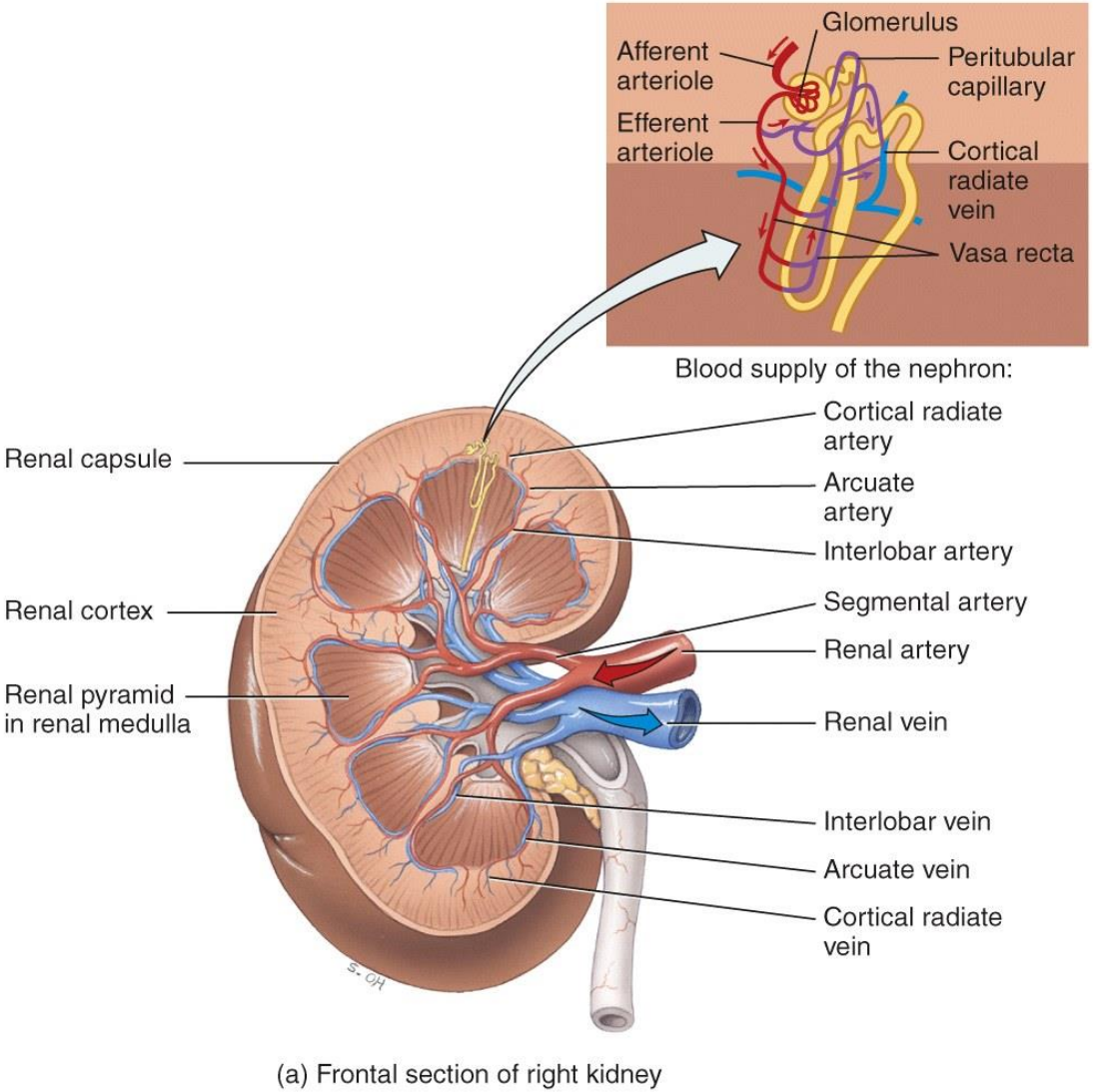


(a) Frontal section of right kidney

Blood Supply of the Kidney

- Renal artery
  - Afferent vessels receive 20–25% of resting cardiac output from abdominal aorta
- Segmental arteries
  - Branches within renal sinus
- Interlobar arteries and veins
  - In renal column, between adjacent renal pyramids
- Arcuate arteries and veins
  - At pyramid base, between renal medulla and cortex
- Cortical radiate arteries and veins
  - Within renal cortex
- Afferent arteriole
  - One per nephron
- Glomerulus
  - Network of capillaries to filter blood for urine formation
  - Unique because between two arterioles
- Efferent arteriole
  - One per nephron
- Peritubular capillaries
  - Some of which form loop of Vasa recta in renal medulla
- Renal vein
  - Efferent vessels carry blood to inferior vena cava

Path of Blood Flow



(a) Frontal section of right kidney

Lesson 4: Anatomy of the Nephron

Objective:

Describe the anatomy and function of the nephron

Explain ion concent5ration in the formation of urine

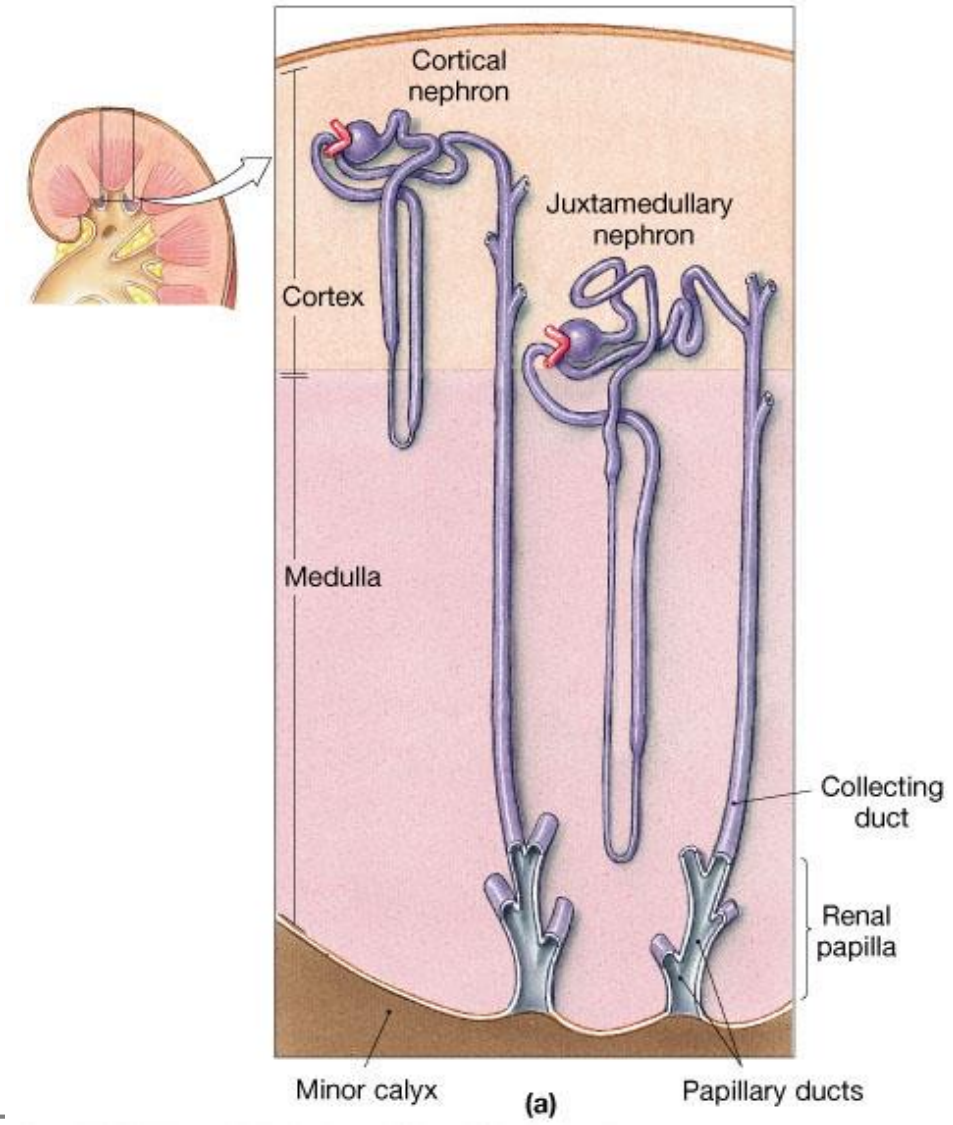
The Nephron

There are two types of nephron

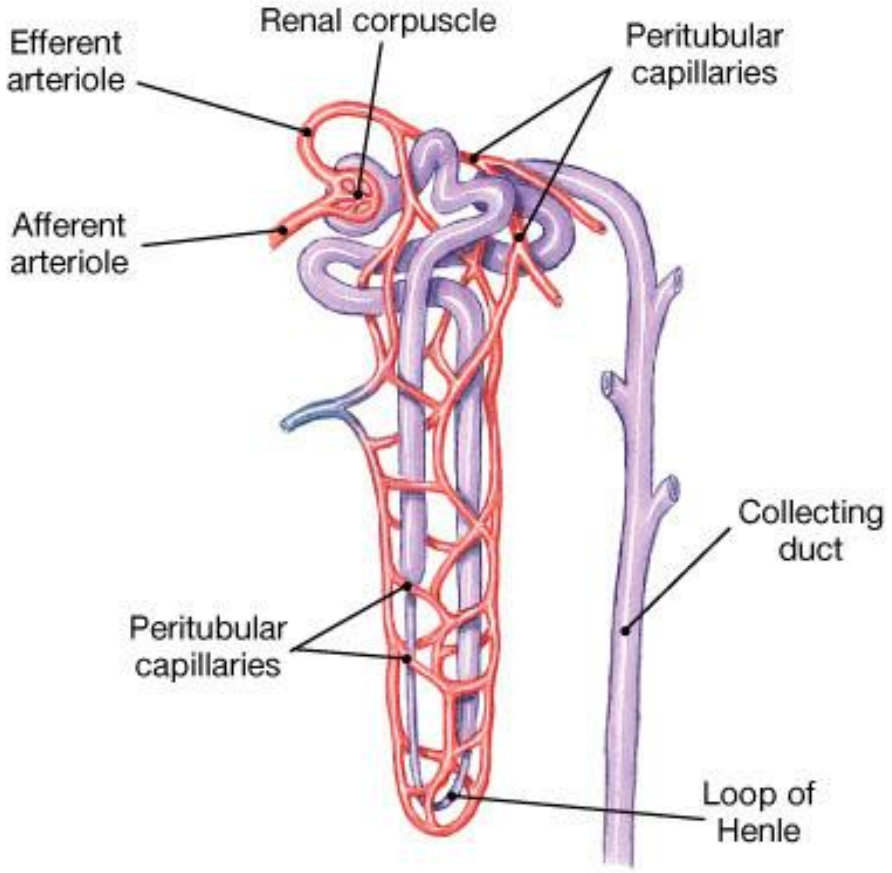
- 1) Cortical nephrons
  - ~85% of all nephrons
  - Located in the cortex

- 2) Juxtamedullary nephrons
  - Closer to renal medulla
  - Loops of Henle extend deep into renal pyramids

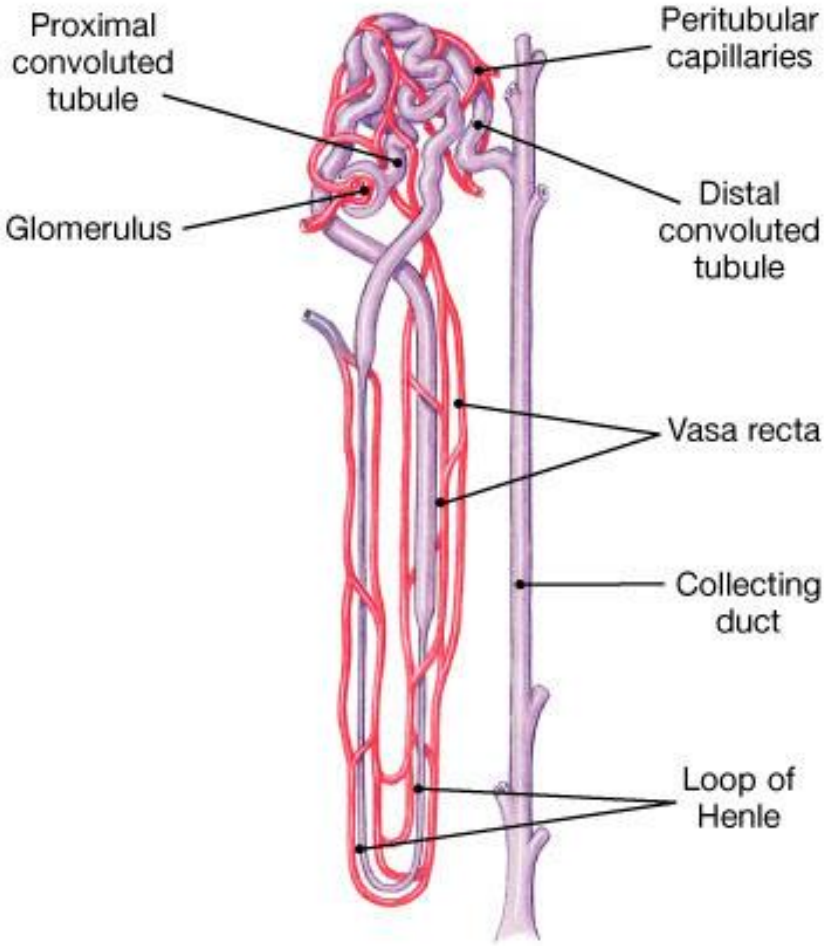
Cortical and Juxtamedullary Nephrons



Cortical and Juxtamedullary Nephrons



(b) Cortical nephron



(c) Juxtamedullary nephron

Nephron Functions

1) Production of filtrate – this occurs at the corpuscle of the nephron

2) Reabsorption of organic nutrients – this occurs at the tubular passageway of the nephron

3) Reabsorption of water and ions - this occurs at the tubular passageway of the nephron

4) Secretion of waste products into tubular fluid - this occurs at the tubular passageway of the nephron

Filtration and Reabsorption

Filtration in the kidneys modified by carrier mediated transport

- Facilitated diffusion
- Active transport
- Cotransport
- Countertransport

Reabsorption and secretion is accomplished via:

- Diffusion,
- Osmosis, and
- Carrier-mediated transport

- The **Nephron** consists of :
  - 1) Renal corpuscle – the head of the nephron
    - **Bowman's capsule** -cover of the corpuscle that surrounds the glomerulus
    - **Glomerulus-** the network of capillaries found inside the corpuscle
      - Blood arrives at glomerulus by way of an **afferent arteriole** and departs in an **efferent arteriole**
  - 2) Renal tubule – the tubular passageway of the nephron
    - The renal tubule consists of
      - **Proximal convoluted tubule (PCT)**
      - **Loop of Henle**
      - **Distal convoluted tubule (DCT)**

Renal function

- Most regions of the nephron perform a combination of functions
- General functions can be identified
  - Filtration in the renal corpuscle
  - Nutrient reabsorption along the PCT
  - Active secretion at PCT and DCT
  - Loops of Henle regulate final volume and solute concentration

Filtrate is Produced

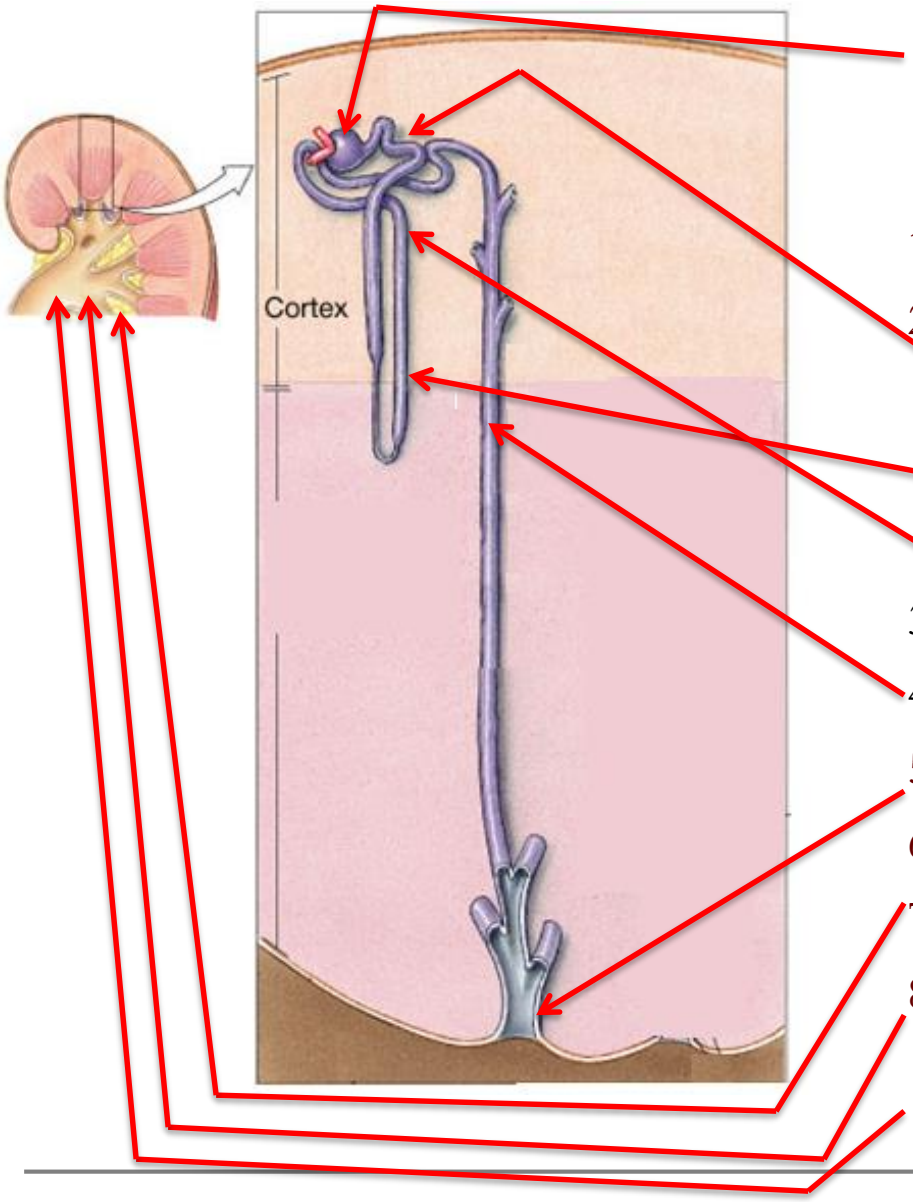
- In renal corpuscle, blood pressure forces fluid and dissolved solutes out of the glomerular capillaries and into the *capsular space*. This process is called ***filtration***
  - **Filtrate**: similar to plasma but without proteins(contains organic substrates- glucose, fatty acids, amino acids), vitamins, water, electrolytes, waste product and other solutes
  - Organic substrates, most water, most electrolytes and vitamins are recaptured (re-absorbed) by the renal tubes, before filtrate leaves the kidneys

From the renal corpuscle, filtrate enters the tubular passageway of the nephron

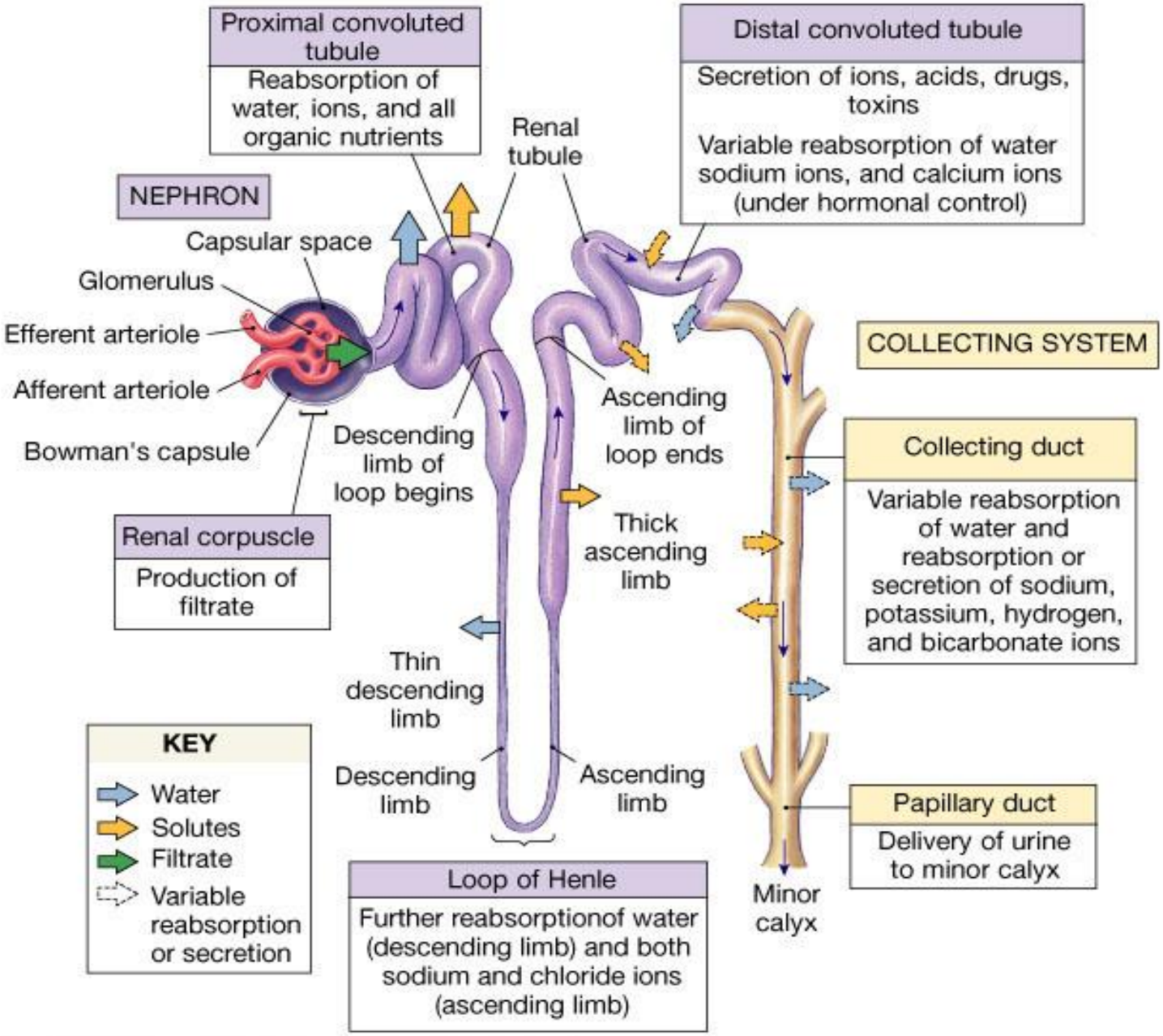
- The tubular passageway of the nephron is responsible for:
  1. Reabsorbing organic substrates and vitamins
  2. Reabsorbing water and electrolytes
  3. Secreting waste products

- Fluid enters into the collecting system from the tubular passageway of the nephron
- Collecting ducts carry the fluid to papillary ducts
- Papillary ducts carry the fluid (urine) to the minor calyx
- Minor calyx carry the fluid (urine) to major calyx
  - Number of minor calyces join together to form a major calyx
- Major calyx deliver the fluid (urine) to renal pelvis
- Renal pelvis is connected to the ureter
- Ureter transports the urine to the bladder

Summary of fluid flow from the nephron to the Ureter



1) Renal corpuscle - capsular space.
2) Tubular passageway of the nephron
   - PCT
   - Lube of Henle
   - DCT
3) Collecting duct
4) Papillary ducts
5) Minor calyx
6) Major calyx
7) Renal pelvis
8) Ureter


Proximal convoluted tubule
Reabsorption of water, ions, and all organic nutrients
Renal tubule
Distal convoluted tubule
Secretion of ions, acids, drugs, toxins
Variable reabsorption of water sodium ions, and calcium ions (under hormonal control)
NEPHRON
Capsular space
Glomerulus
Efferent arteriole
Afferent arteriole
Bowman's capsule
COLLECTING SYSTEM
Ascending limb of loop ends
Descending limb of loop begins
Collecting duct
Variable reabsorption of water and reabsorption or secretion of sodium, potassium, hydrogen, and bicarbonate ions
Renal corpuscle
Production of filtrate
Thick ascending limb
Thin descending limb
KEY
Water
Solutes
Filtrate
Variable reabsorption or secretion
Descending limb
Ascending limb
Papillary duct
Delivery of urine to minor calyx
Loop of Henle
Further reabsorptionof water (descending limb) and both sodium and chloride ions (ascending limb)
Minor calyx

Tubular Reabsorption and Secretion Hormonal Regulation Overview

- Renin – Angiotensin – Aldosterone System
  - Regulate electrolyte reabsorption and secretion
- Antidiuretic hormone (AH)
  - Regulates water reabsorption
- Atrial natriuretic peptide
  - Inhibits electrolyte and water reabsorption
- Parathyroid hormone
  - Stimulates DCT cells to reabsorb more Ca^{2+}

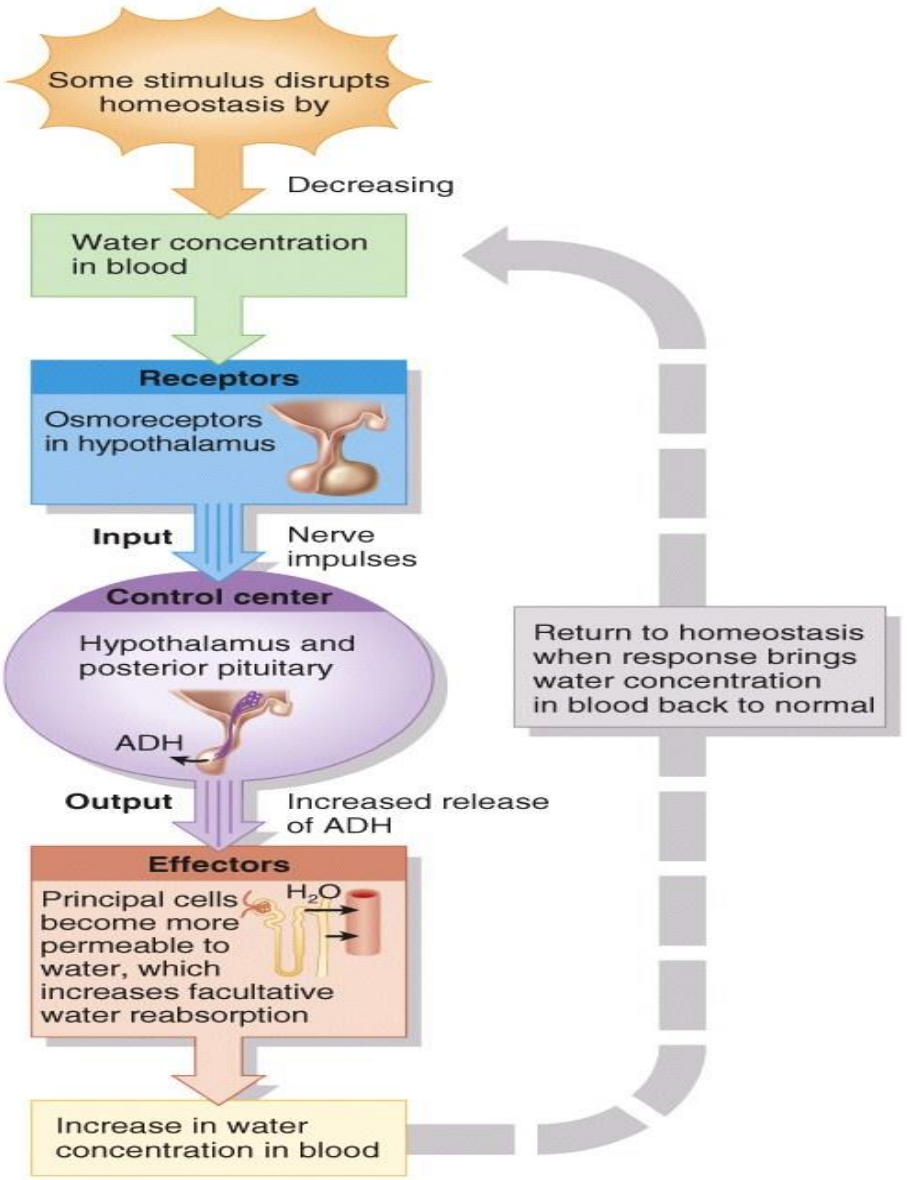
Renin-Angiotensin-Aldosterone System

- Blood pressure decrease stimulates release of renin **from** juxtaglomerular cells
- Renin converts angiotensinogen into Angiotensin I
- ACE activates Angiotensin I to Angiotensin II
  - Decreases glomerular filtration rate
  - Enhances PCT reabsorption of Na^+, Cl^-, and water
  - Stimulates release of aldosterone to reabsorb more Na^+, Cl^-, and water by principal cells
- Net result: blood volume/pressure increases

Antidiuretic Hormone/Vasopressin

- ADH release **from** posterior pituitary stimulated by decreased:
  - Water concentration in blood (osmoreceptors)
  - Blood volume (baroreceptors)
- ADH regulates facultative water reabsorption
  - Inserts aquaporins into apical membranes of principal cells
  - basolateral membranes always permeable so water moves into capillaries
- Net result: production of concentrated urine to maintain fluid homeostasis

Negative Feedback Mechanism Regulating Water Reabsorption by ADH



Atrial Natriuretic Peptide

- Released **from** heart in response to large increase in blood volume
- Inhibits Na^+ and water reabsorption in PCT
- Suppresses secretion of aldosterone and ADH
- Net result: increased urine output to decrease blood volume and blood pressure

Parathyroid Hormone

- Released **from** parathyroid gland in response to drop in blood Ca^{2+} levels
- Stimulates cells in DCT to reabsorb more Ca^{2+}
- Inhibits phosphate reabsorption in PCT
- Net result: increased blood calcium without increased phosphate

Lesson 5: Urine

Objective:

Describe how normal urine consists of water, urea, salts and pigments

Urine production maintains homeostasis

- Regulating blood volume and composition by excreting or reabsorbing water, sodium, hydroge and other electrolyte
- Excreting waste products such as:
  - Urea
  - Creatinine
  - Uric acid

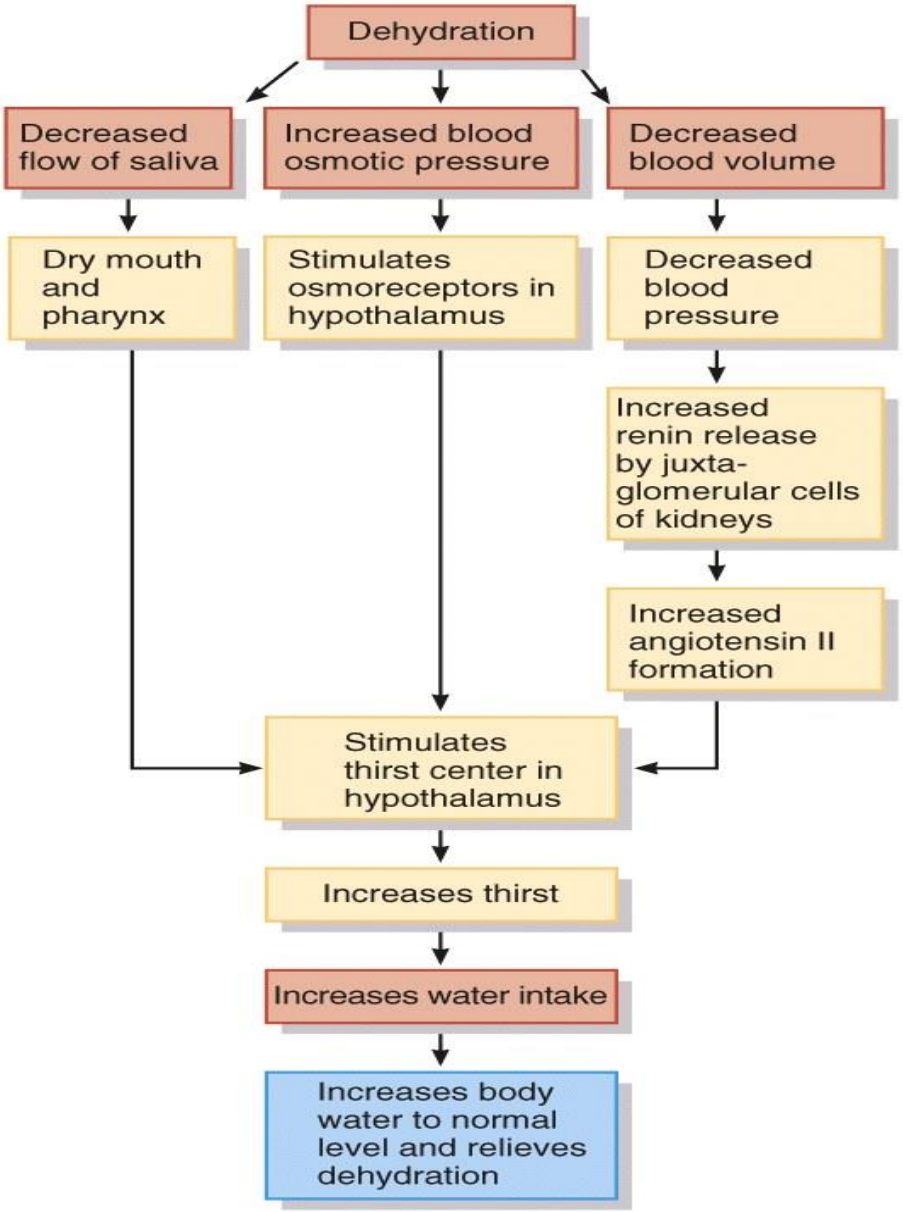
Recall How Urine is Formed

1) Filtration –
   - blood pressure forces fluid and dissolved solutes out of the glomerular capillaries and into the capsular space
2) Reabsorption –
   - reabsorb water and solutes from the filtrate
3) Secretion –
   - Transport of solutes from the peritubular fluid into the tubular fluid

Fluid Balance

- When required amounts of water and solutes or electrolytes are present and correctly distributed throughout the body
  - Intracellular - cytosol/fluid within cells
  - Extracellular - interstitial tissue fluid between cells, blood plasma, lymph and other fluids of body cavities
- Kidneys maintain fluid homeostasis by excreting dilute or concentrated urine
- Fluid gain/loss changes blood volume and pressure

Regulation of Water Gain



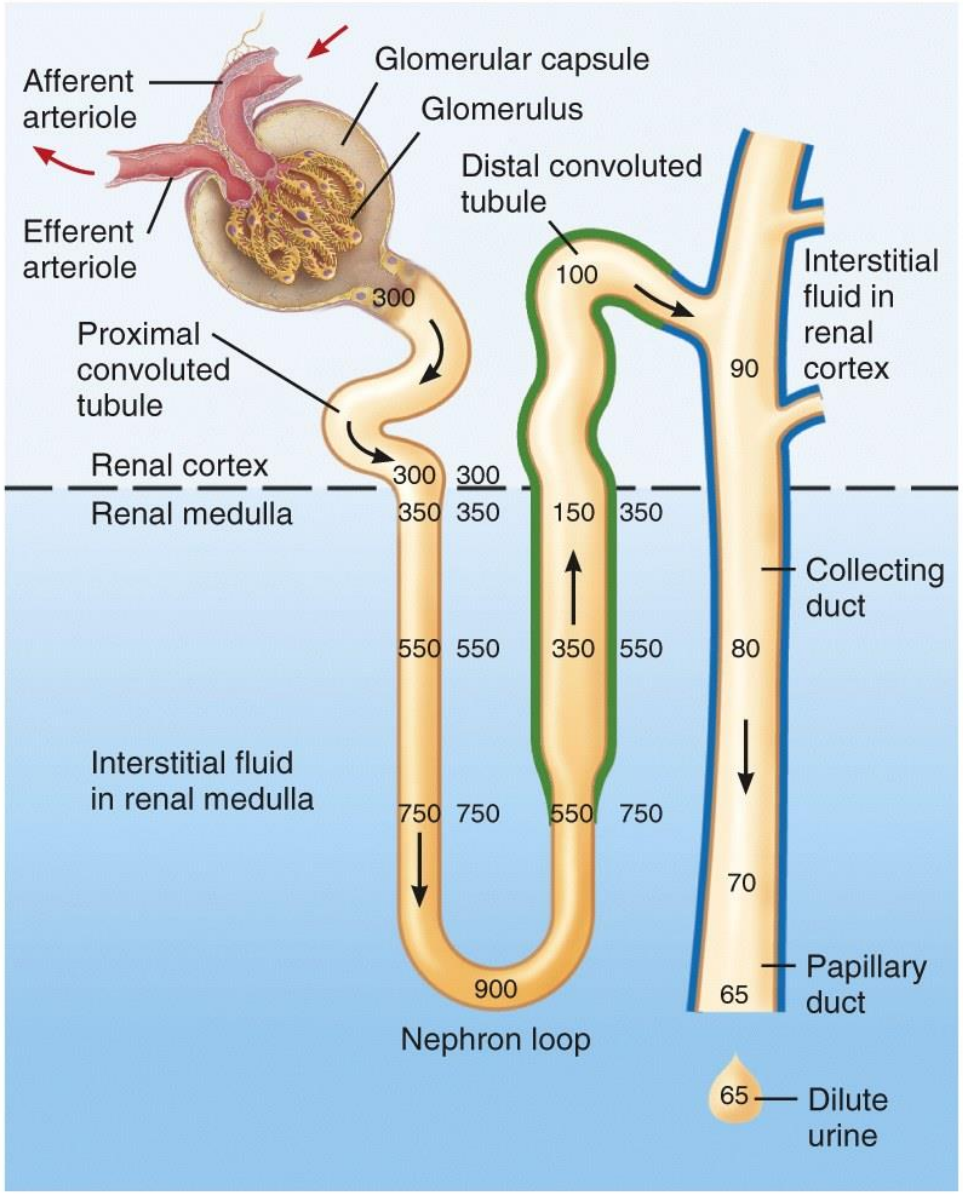
Formation of Dilute Urine

- PCT lumen fluid remains isotonic to blood plasma by obligatory water reabsorption following solutes
- Descending limb of nephron loop reabsorbs more water passively into renal pyramid interstitial fluid making fluid in lumen more concentrated
- Ascending limb of nephron loop impermeable to water, so Na^+, K^+ and Cl^- ion reabsorption by symporters makes the fluid in lumen more dilute than blood plasma

Formation of Dilute Urine

- Early DCT not very permeable to water, so as more solute reabsorbed, fluid in lumen more dilute
- Late DCT and collecting duct impermeable to water when ADH normally low, so continued solute reabsorption makes fluid draining into minor calyx up to 4 times more dilute than blood plasma

Formation of Dilute Urine



Formation of Concentrated Urine

- ADH allows concentration of tubular fluid due to increasing osmotic gradient of solutes in interstitial fluid from renal cortext to medulla
- Three major solutes contribute to this gradient: Na^+, Cl^-, and urea
- Two major factors establish/maintain this gradient:
  - Different water permeability and solute reabsorption in different sections of loop
  - Countercurrent fluid flow in loop and vasa recta

Formation of Concentrated Urine

- Symporters in ascending limb create buildup of Na^+ and Cl^- in renal medulla
- Different permeability as countercurrent flow in descending and ascending limbs
  - Descending very permeable to water but impermeable to most solutes
  - Ascending reabsorb Na^+ and Cl^- but impermeable to water
  - Net result: tubular fluid becomes more concentrated as flows down into medulla but becomes more dilute as flows back up to cortex

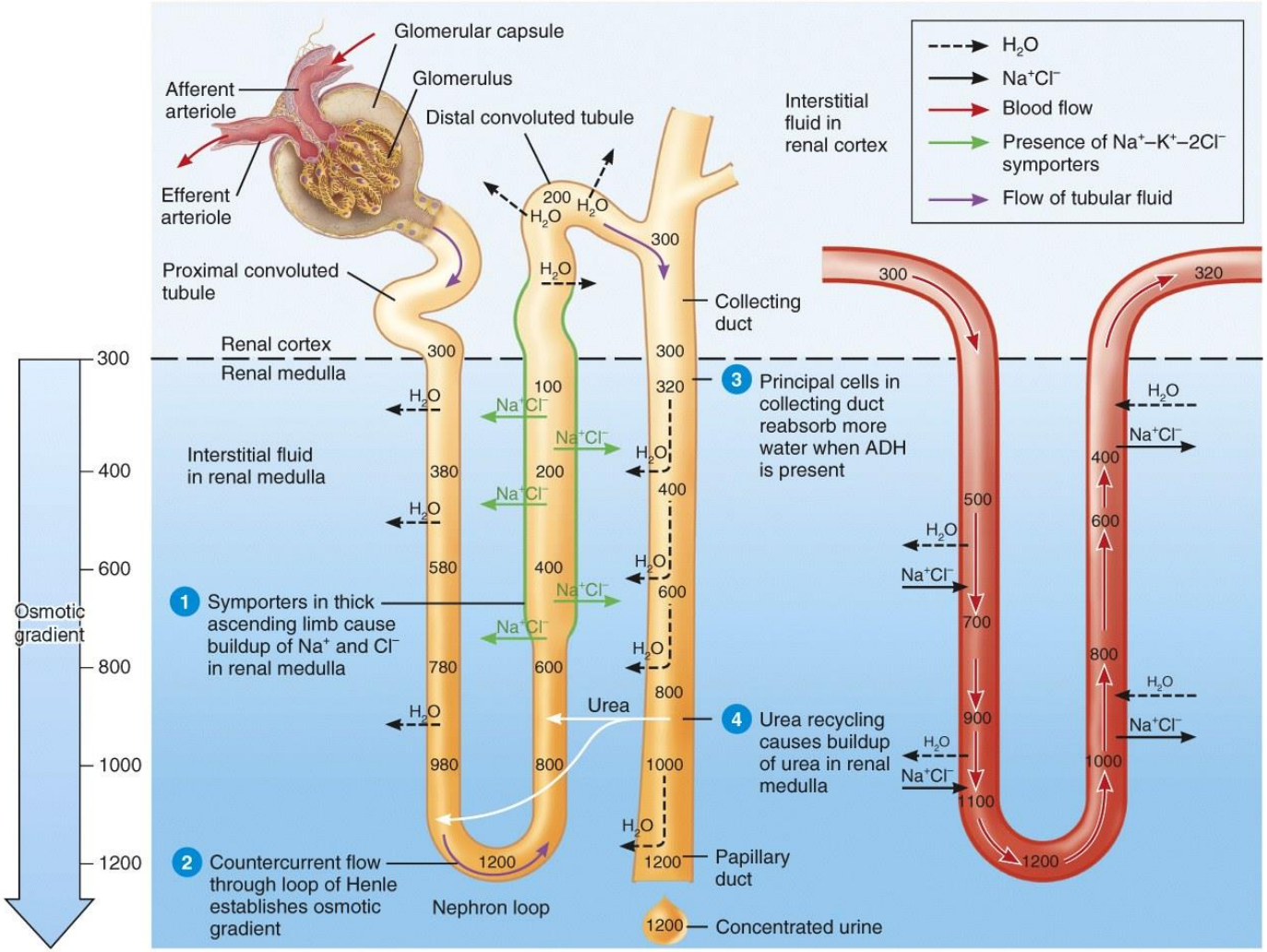
Formation of Concentrated Urine

- Under influence of ADH, principal cells in collecting duct become permeable to water
- As collecting duct fluid passes through increasing osmotic gradient, more water reabsorbed
- Urea recycling causes buildup in renal medulla, promoting more water reabsorption
  - Collecting duct permeable, so reabsorbed
  - Descending and thin ascending loop permeable, so secreted into tubule lumen again

Formation of Concentrated Urine

- Vasa recta countercurrent provides oxygen and nutrients to renal medulla without diminishing osmotic gradient
- Net result in renal medulla:
  - Nephron loop (especially juxtamedullary) establishes osmotic gradient
  - Urea recycling enhances osmotic gradient
  - Vasa recta maintains the osmotic gradient
  - ADH changes collecting duct permeability to regulate rate of water loss in urine

Formation of Concentrated Urine



RENAL CORPUSCLE

Glomerular filtration rate: 105–125 mL/min of fluid that is isotonic to blood

Filtered substances: water and all solutes present in blood (except proteins) including ions, glucose, amino acids, creatinine, uric acid

PROXIMAL CONVOLUTED TUBULE

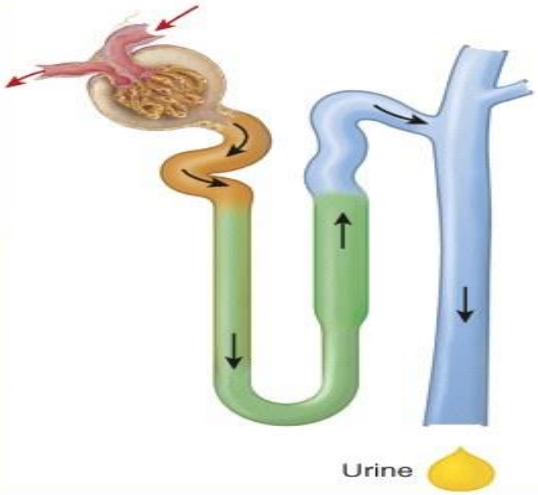
Reabsorption (into blood) of:

Water	65% (osmosis)
Na^+	65% (sodium–potassium pumps, symporters, antiporters)
K^+	65% (diffusion)
Glucose	100% (symporters and facilitated diffusion)
Amino acids	100% (symporters and facilitated diffusion)
Cl^-	50% (diffusion)
HCO_3^-	80–90% (facilitated diffusion)
Urea	50% (diffusion)
Ca^{2+}, Mg^{2+}	variable (diffusion)

Secretion (into urine) of:

H^+	variable (antiporters)
NH_4^+	variable, increases in acidosis (antiporters)
Urea	variable (diffusion)
Creatinine	small amount

At end of PCT, tubular fluid is still isotonic to blood (300 mOsm/liter).



NORMAL CHARACTERISTICS OF URINE

Volume	one to two liters per 24 hours; considerable variation in normal volume
Color	yellow or amber color; color is darker in concentrated urine
Turbidity	transparent in freshly voided urine; microbes, pus, epithelial cells, or crystals may cause cloudiness
Odor	aromatic when fresh; ammonia-like after standing because of breakdown of urea to ammonia by bacteria
pH	normal range is 4.6–8.0; high protein diets produce an acidic urine; vegetarian diets produce an alkaline urine
Specific gravity	normal range is 1.001–1.035; low specific gravity represents dilute urine, higher values represent a concentrated urine

NEPHRON LOOP

Reabsorption (into blood) of:

Water	15% (osmosis in descending limb)
Na^+	20–30% (symporters in ascending limb)
K^+	20–30% (symporters in ascending limb)
Cl^-	35% (symporters in ascending limb)
HCO_3^-	10–20% (facilitated diffusion)
Ca^{2+}, Mg^{2+}	variable (diffusion)

Secretion (into urine) of:

Urea	variable (recycling from collecting duct)

At end of nephron loop, tubular fluid is hypotonic (100–150 mOsm/liter).

DISTAL CONVOLUTED TUBULE AND COLLECTING DUCT

Reabsorption (into blood) of:

Water	20% (osmosis, water channels stimulated by ADH)
Na^+	5–15% (symporters, sodium–potassium pumps, sodium channels stimulated by aldosterone)
Cl^-	5% (symporters)
HCO_3^-	variable, depends on H^+ secretion (antiporters)
Urea	variable (recycling of nephron loop)
Ca^{2+}	variable (stimulated by parathyroid hormone)

Secretion (into urine) of:

K^+	variable, adjusts to dietary intake (leakage channels)
H^+	variable, adjusts to maintain acid–base homeostasis (H^+ pumps)

Tubular fluid leaving the collecting duct is dilute when ADH level is low and concentrated when ADH level is high.