DIGESTIVE SYSTEM HISTOLOGY

General Structure and Functions of the Digestive System

- Organs of the Digestive System to:
  - Ingest the food.
  - Transport the food.
  - Digest the food into smaller usable components.
  - Absorb the necessary nutrients into the bloodstream.
  - Expel the waste products from the body.

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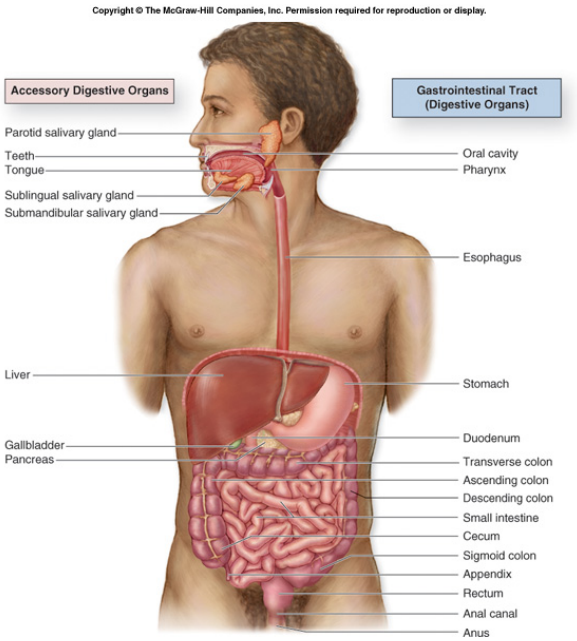
General Structure and Functions of the Digestive System

- Composed of two separate categories of organs:
  - digestive organs
  - accessory digestive organs.
- Digestive organs collectively make up the:
  - gastrointestinal (GI) tract.
  - Also called:
    - the digestive tract
    - alimentary canal.



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General Structure and Functions of the Digestive System

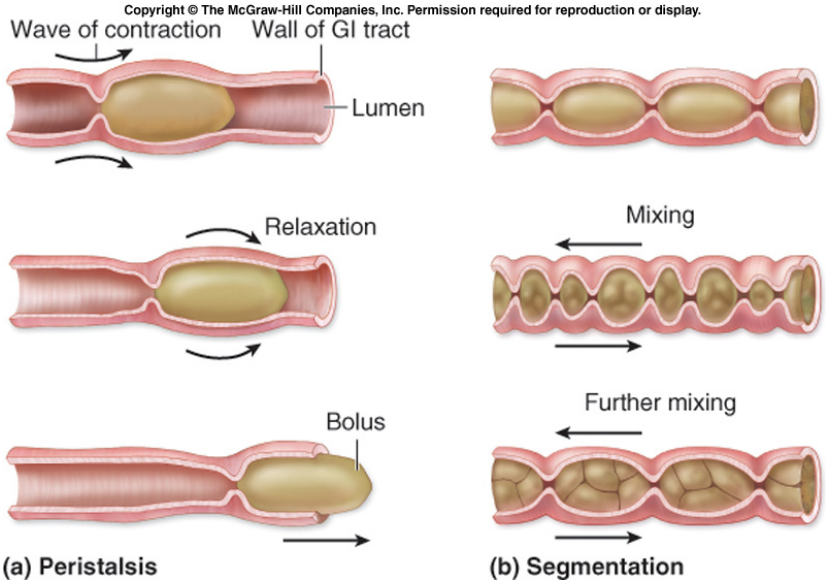
- The GI tract organs:
  - oral cavity
  - pharynx
  - esophagus
  - stomach
  - small intestine
  - large intestine
- continuous tube
  - about 30 feet (9–10 meters)
  - from mouth to anus.
- Smooth muscle in the wall
  - responsible for motility
  - pushes materials from one end to the other.

General Structure and Functions of the Digestive System

- Accessory digestive organs:
  - do not form the GI tube
  - can develop as outgrowths
  - are connected to the GI tract (some by ducts)
- Assist the GI tract in the digestion of food.
- Include:
  - Teeth
  - Tongue
  - Salivary glands
  - Liver
  - Gallbladder
  - Pancreas

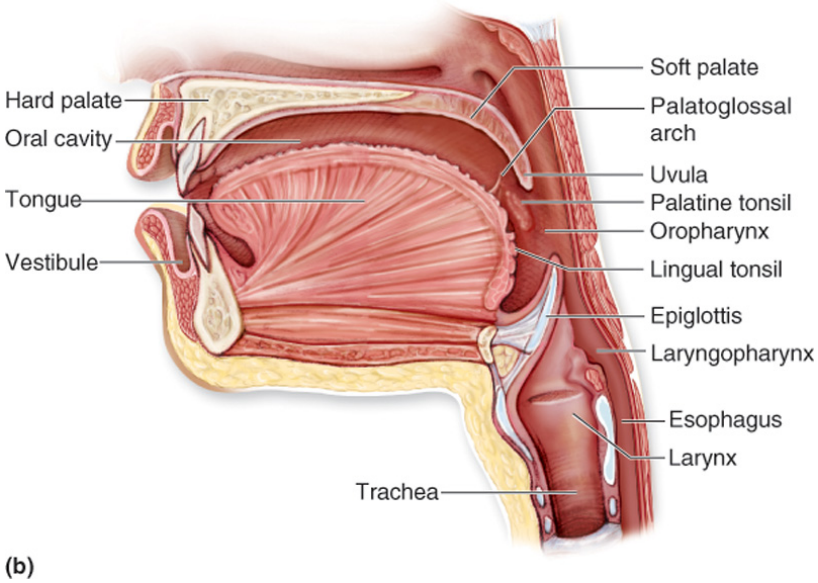
Digestive System Functions

- Ingestion
- Digestion: break down of large particles of food
  - **mechanical digestion**
  - **chemical digestion**
- Propulsion
  - peristalsis
  - segmentation
- Secretion:
  - digestive enzymes
  - hormones
- Absorption:
  - from external environment into internal environment
  - across mucosa
- Elimination of wastes (defecation)



Oral Cavity (mouth)

- Entrance to the GI tract.
- Initial site of digestion:
  - mechanical digestion (via mastication)
  - chemical digestion (via enzymes in saliva).
- Bounded anteriorly by the teeth and lips
- Bounded posteriorly by the oropharynx.
- Superior boundary is formed by the hard and soft palates.
- Floor, or inferior surface, of the oral cavity
  - the tongue
  - the mylohyoid muscle covered with mucosa.



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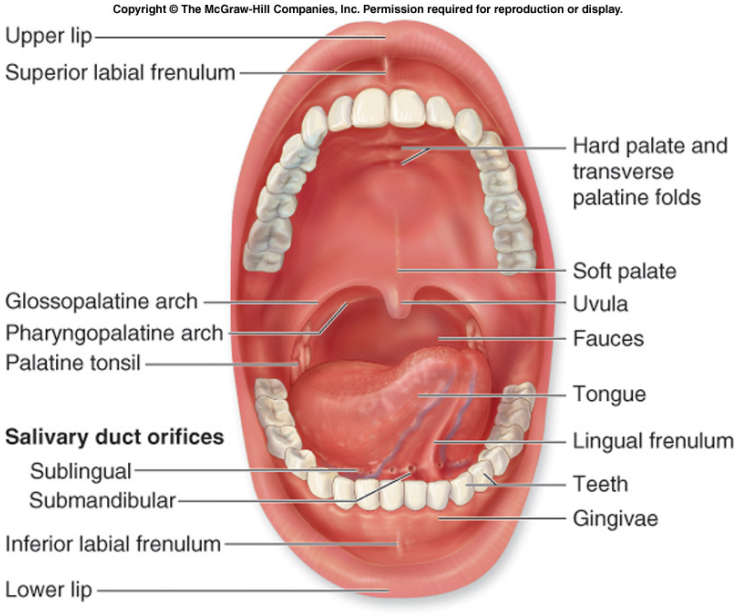
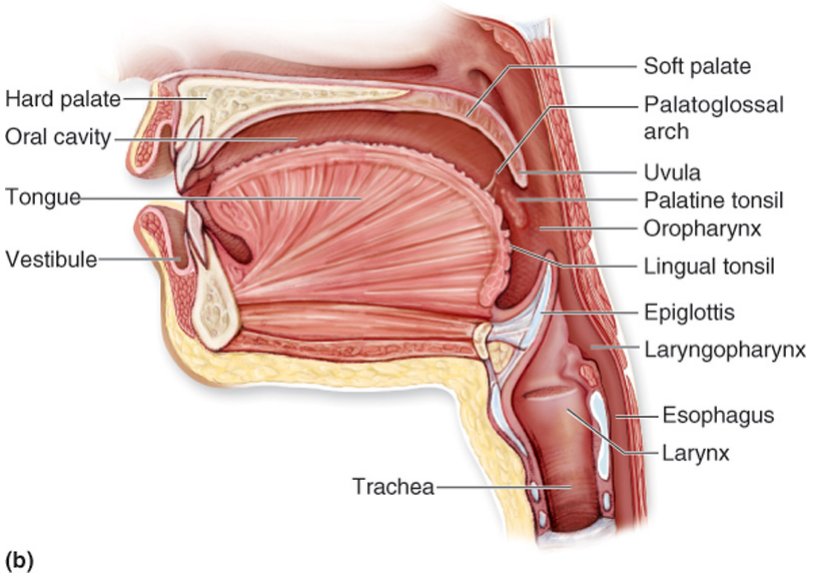
Oral Cavity (mouth)

- Two regions of the oral cavity
  - Vestibule is the space between the cheeks or lips and the gums.
  - Oral cavity proper.
- The lateral walls are formed by the cheeks.
  - Contain buccinator muscles
- Lips (labia).
  - Orbicularis oris muscle
  - Keratinized stratified squamous ET
- Gingivae, or gums.
  - Dense regular CT
  - Nonkeratinized ET
- Labial frenulum.





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Palate

- Hard palate
  - Anterior two-thirds of the palate
  - hard and bony
- Soft palate
  - Posterior one-third
  - soft and muscular
  - primarily composed of skeletal muscle.
  - Extending inferiorly from the posterior part of the soft palate is the uvula.
- When swallowing, the soft palate and the uvula elevate to close off the opening of the nasopharynx.

Palate

- Fauces represent the opening between the oral cavity and the oropharynx.
- Fauces are bounded by paired muscular folds:
  - glossopalatine arch (anterior fold)
  - pharyngopalatine arch (posterior fold)
- Palatine tonsils are housed between the arches.

Tongue

- An accessory digestive organ
- Formed from:
  - skeletal muscle
  - covered with lightly keratinized stratified squamous epithelium.
- Manipulates and mixes ingested materials during chewing
- Forms the bolus.
  - a globular mass of partially digested material
- Performs important functions in swallowing.

Tongue

- Inferior surface of the tongue
  - attaches to the floor of the oral cavity
  - By the lingual frenulum.
- Numerous small projections (papillae) cover the superior (dorsal) surface.
- Posterior surface contains lingual tonsils.
- Skeletal muscles move the tongue.

Salivary Glands

- Collectively produce and secrete saliva.
  - a fluid that assists in the initial activities of digestion
- Volume of saliva secreted daily ranges between 1.0 and 1.5 L.
  - Most is produced during mealtime
  - Smaller amounts are produced continuously to ensure that the oral cavity remains moist.

Salivary Glands

- Components of saliva
  - Water: makes up 99%
  - Amylase: first step of chemical digestion
  - Lysozyme: antimicrobial
- Functions
  - Moisten food
  - Food molecules into solution: taste
  - Form bolus: for swallowing
  - Cleanse oral cavity.

Salivary Glands

- Three pairs of large, multicellular salivary glands:
  - parotid glands
  - submandibular glands
  - sublingual glands

The Parotid Glands

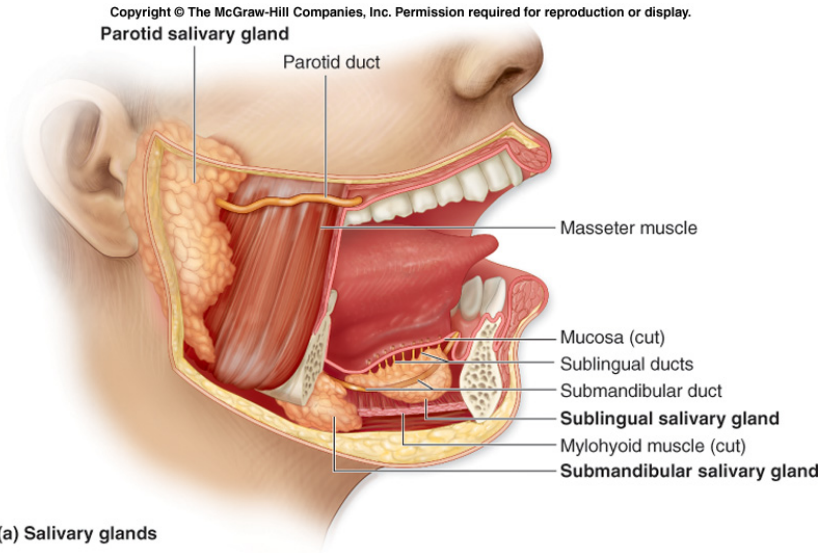
- Largest salivary glands.
  - located anterior and inferior to the ear
  - partially overlying the masseter muscle.
- Produce about 25–30% of saliva
  - conducted through the parotid duct to the oral cavity.

The Submandibular Glands

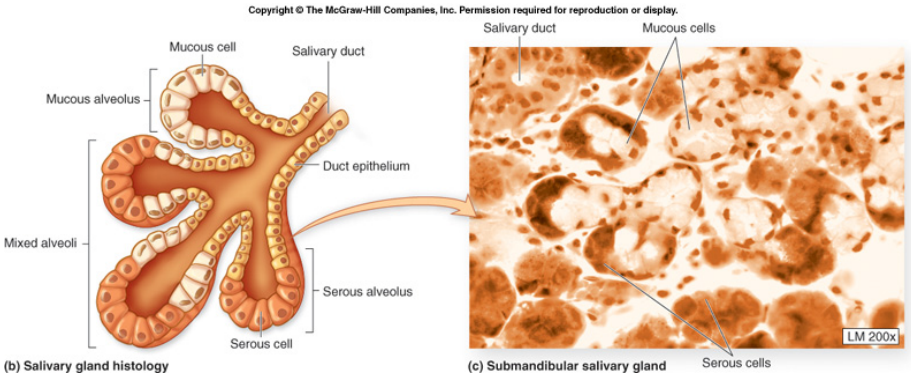
- Inferior to the body of the mandible.
- Produce most of the saliva (about 60–70%).
- ducts opens through a papilla in the floor of the mouth
  - lateral to the the lingual frenulum.

The Sublingual Glands

- Inferior to the tongue
  - internal to the oral cavity mucosa.
- Each gland has multiple tiny sublingual ducts
  - open onto the inferior surface of the oral cavity
  - posterior to the submandibular duct papilla.
- Contribute only about 3–5% of the total saliva.

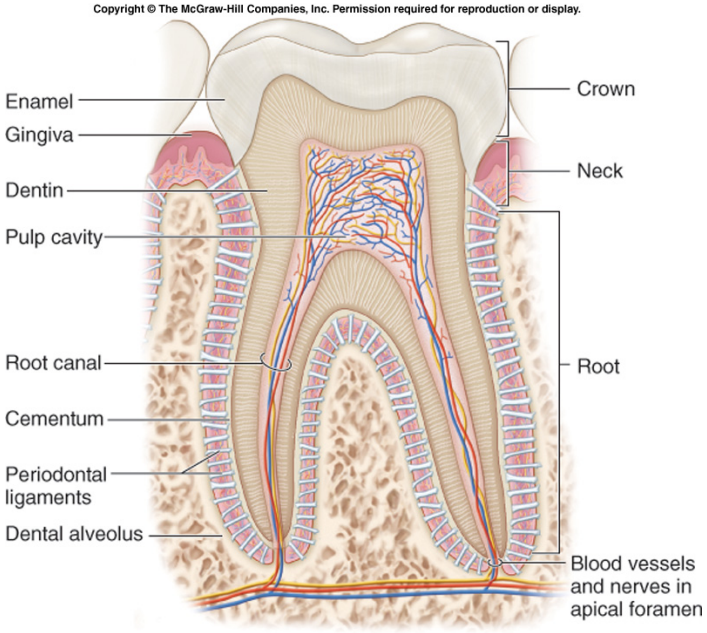


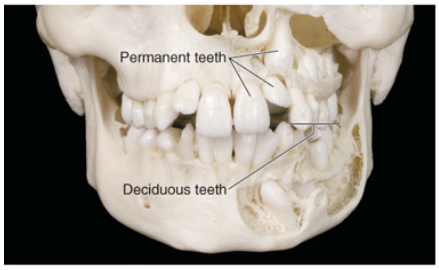
(a) Salivary glands



Teeth

- Collectively known as the dentition.
- Responsible for mastication
  - first part of the mechanical digestion.
- A tooth has:
  - exposed crown
  - constricted neck
  - one or more roots
- Roots of the teeth fit into dental alveoli
  - are sockets within the alveolar processes
  - on both the maxillae and the mandible.
- Collectively, the roots, the dental alveoli, and the periodontal ligament that binds the roots to the alveolar processes form a gomphosis joint.





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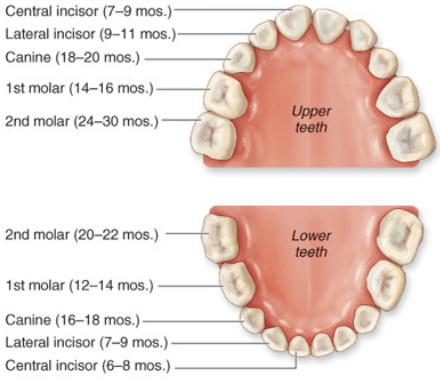
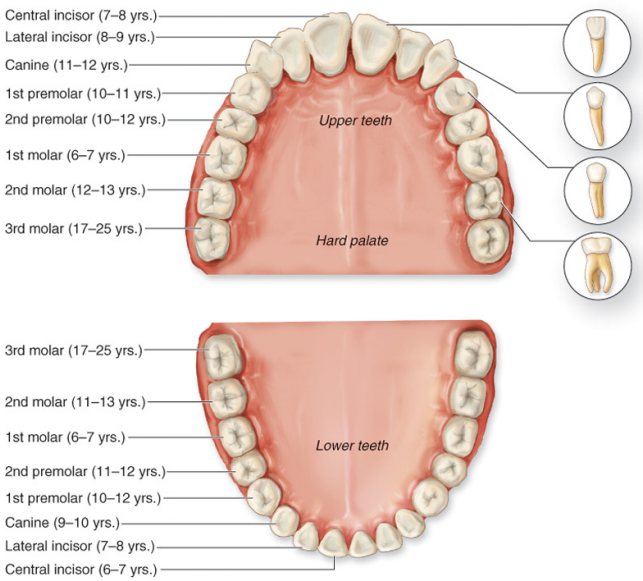


(b) Deciduous teeth



(c) Permanent teeth

Teeth

- Two sets of teeth
- 20 deciduous teeth, also called "milk teeth," erupt between 6 months and 30 months after birth.
- These teeth are eventually lost and replaced by 32 permanent teeth.
- The more anteriorly placed permanent teeth tend to appear first, followed by the posteriorly placed teeth.
- The last teeth to erupt are the third molars, often called "wisdom teeth," in the late teens or early 20's.
- Often the jaw lacks space to accommodate these final molars, and they may either emerge only partially or grow at an angle and become impacted.
- Impacted teeth cannot erupt properly because of the angle of their growth.

Pharynx

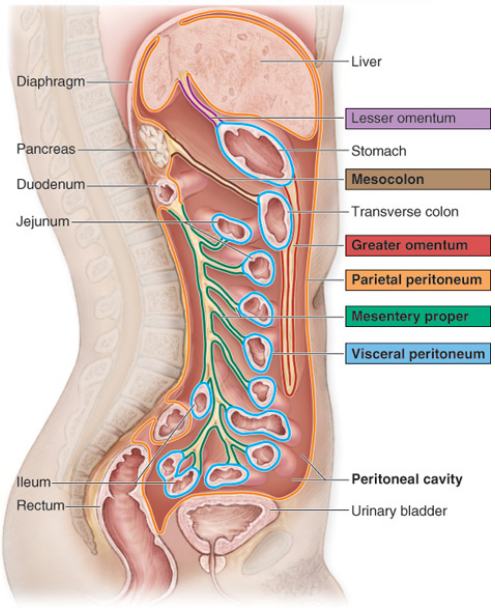
- Review
- Pharyngeal constrictors
- Innervated by the vagus nerves

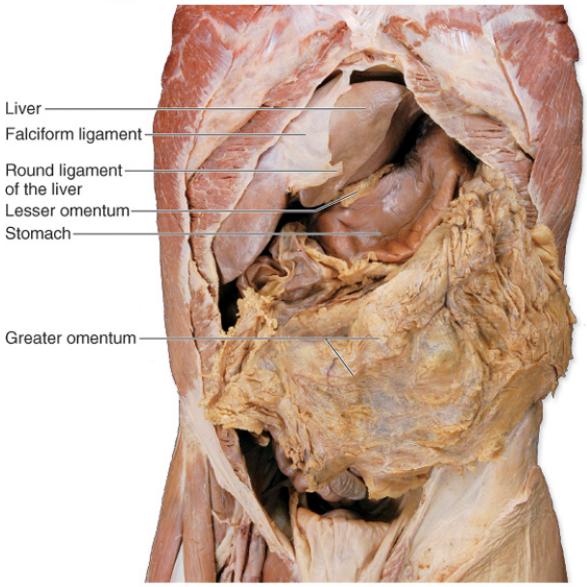
General arrangement of abdominal GI organs

- Peritoneum
  - Parietal peritoneum
  - Visceral peritoneum
  - Peritoneal cavity
- Intraperitoneal organs
- Retroperitoneal organs

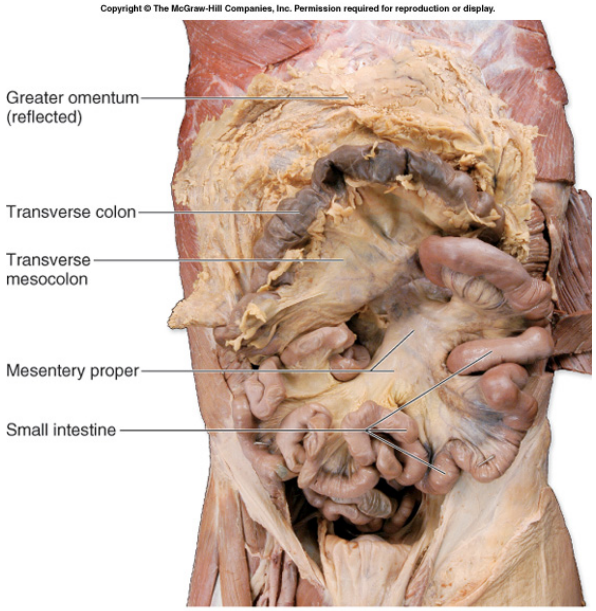
General arrangement of abdominal GI organs

- Mesentaries
  - Double layered folds of peritoneum
- Greater omentum
- Lesser omentum
- Mesentery proper
  - Suspends small intestine from posterior wall of abdomen
- Mesocolon
  - Suspends large intestine
- Peritoneal ligament
  - Peritoneum that attaches one organ to another





(a) Omenta



(b) Mesentery proper and mesocolon

General Histology of GI Organs

- from the esophagus through the large intestine
  - a tube
  - composed of four concentric layers called tunics.
- From deep to superficial, these tunics are:
  - the mucosa
  - the submucosa
    - submucosal nerve plexus (Meissner plexus)
  - the muscularis
    - myenteric plexus (Auerbach plexus)
  - the adventitia or serosa

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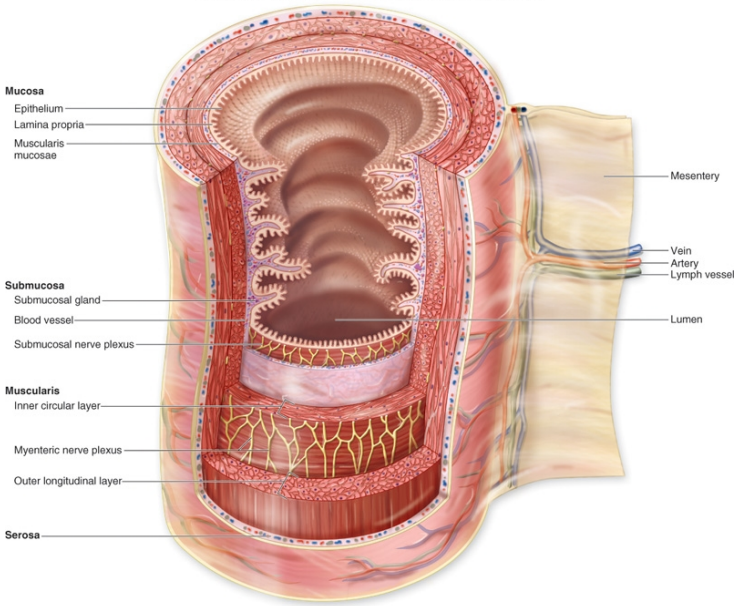

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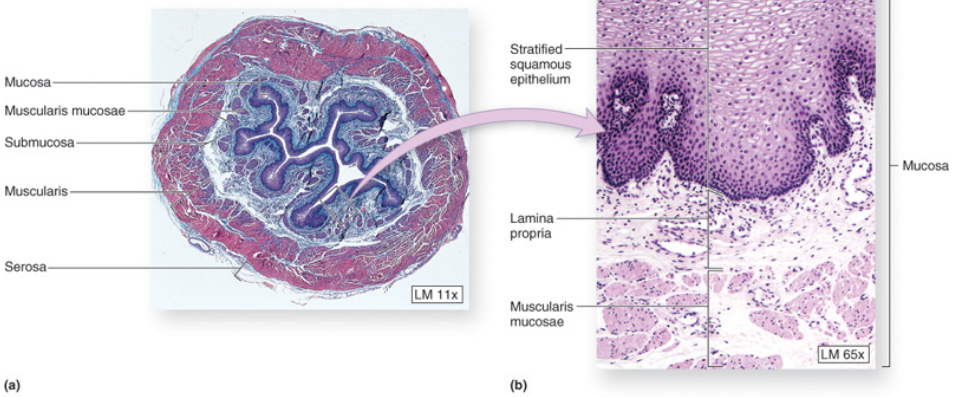
Esophagus

- Tubular passageway
  - Pharynx to stomach
  - Bolus
  - About 25 cm in adult
  - Esophageal hiatus: through diaphragm
- Histology
  - Mucosa: nonkeritinized stratified squamous ep.
  - Submucosa: thick, elastic fibers, mucous glands
  - Muscularis: inner circular, outer longitudinal
    - Both skeletal and smooth
  - Adventitia



Esophagus

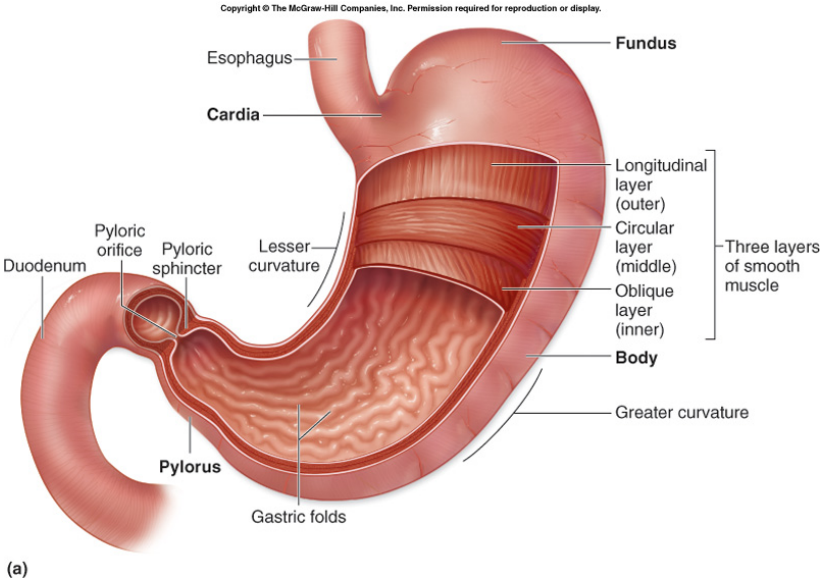
- Superior esophageal sphincter:
  - Skeletal muscle
  - Where pharynx and esophagus meet
- Inferior esophageal sphincter
  - Also cardiac sphincter
  - Circular smooth muscle
  - Orifice between esophagus and stomach

Stomach

- General
  - J-shaped
  - Functions
    - Digestion
      - Chemical
      - Mechanical
    - Results in chyme
    - Limited absorption

Stomach

- Gross anatomy
  - Cardia
    - Cardiac orifice
  - Fundus
  - Body
  - Pylorus
    - Pyloric sphincter
    - Pyloric orifice
  - Greater curvature
    - Greater omentum
  - Lesser curvature
    - Lesser omemtum
  - Gastric folds (rugae)



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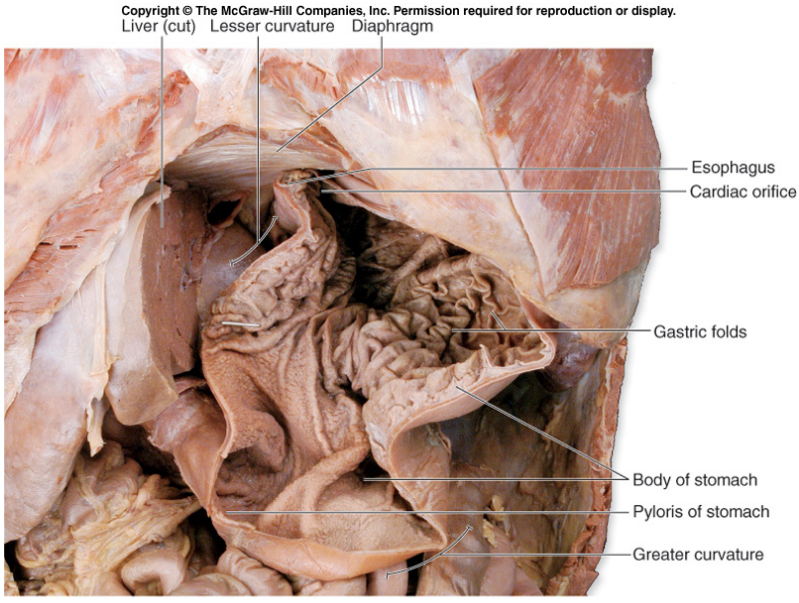
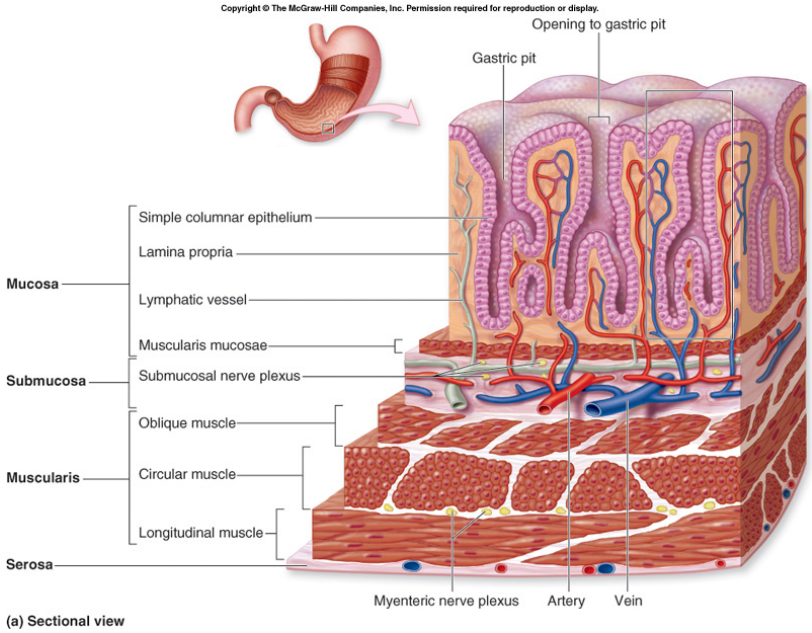
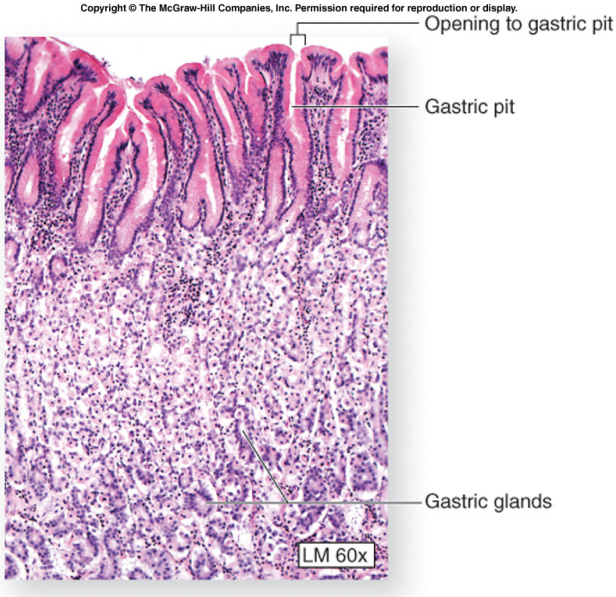


Stomach

- Histology
  - Mucosa: simple columnar
    - Gastric pits
    - Gastric glands
  - Muscularis
    - 3 layers
      - Inner oblique
      - Middle circular
      - Outer longitudinal



(a) Sectional view



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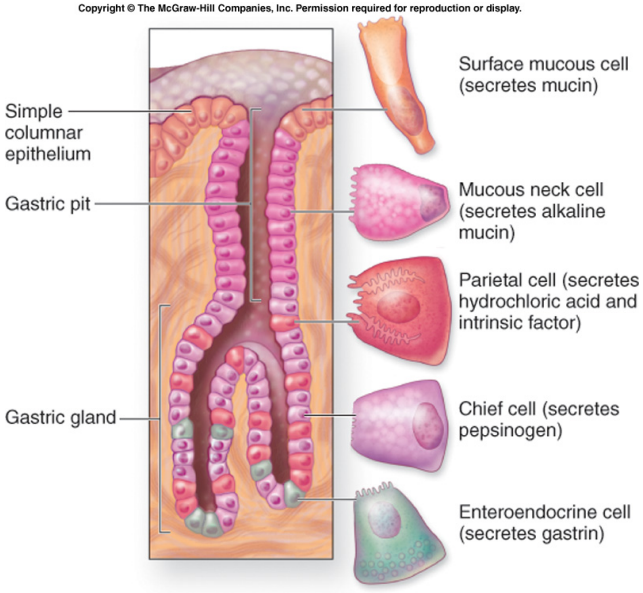


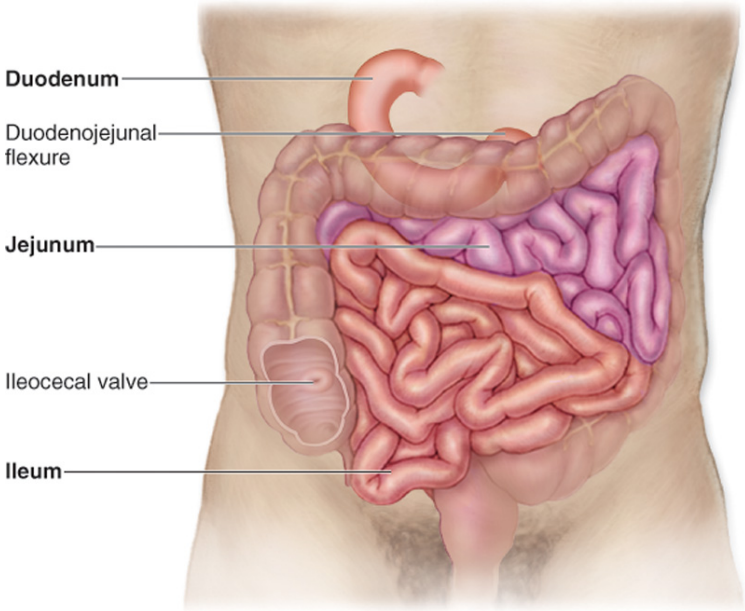
(c) Gastric pit and gland

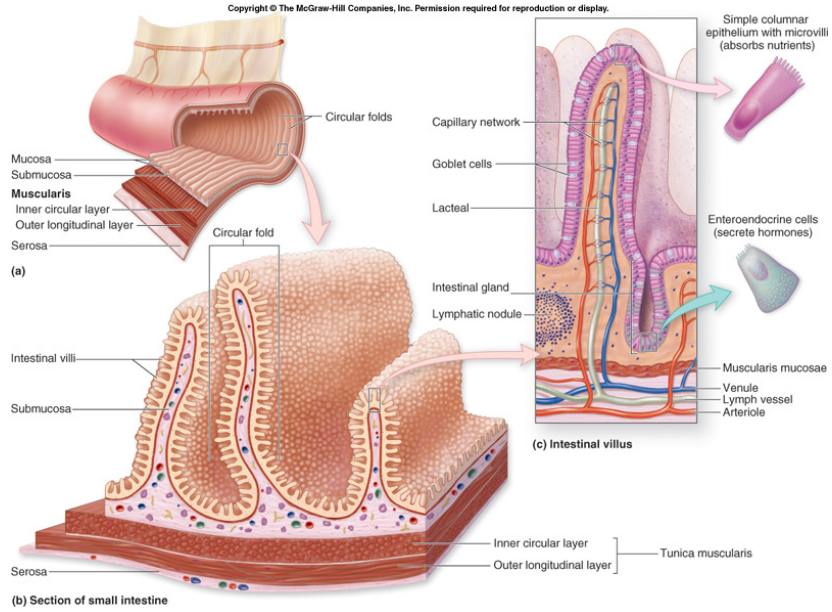
Small Intestine

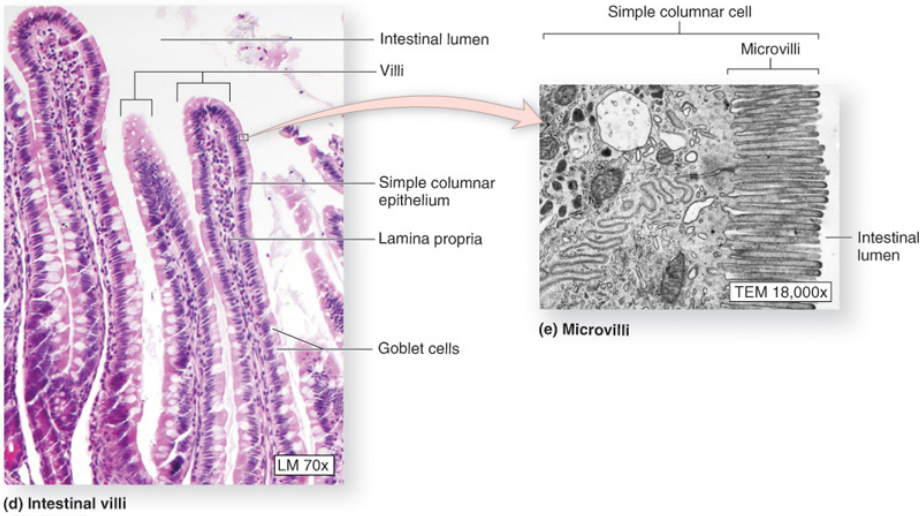
- Finishes chemical digestion
- Responsible for absorbing most of the nutrients.
  - Ingested nutrients spend at least 12 hours in the small intestine.
- thin-walled tube
  - about 6 meters (20 feet) in length.
  - coiled
- Extends from the pylorus of the stomach to the cecum of the large intestine
  - occupies a significant portion of the abdominal cavity.

Small Intestine

- The duodenum
  - first segment of the small intestine.
  - approximately 25 centimeters (10 inches) long
  - originates at the pyloric sphincter
  - major duodenal papilla
- The jejunum
  - middle region of the small intestine.
  - approximately 2.5 meters (7.5 feet)
  - makes up approximately two-fifths of the small intestine's total length.
  - primary region for chemical digestion and nutrient absorption
- The ileum
  - is the last region of the small intestine.
  - about 3.6 meters (10.8 feet) in length
  - forms approximately three-fifths of the small intestine.
  - terminates at the ileocecal valve
    - sphincter that controls the entry of materials into the large intestine.

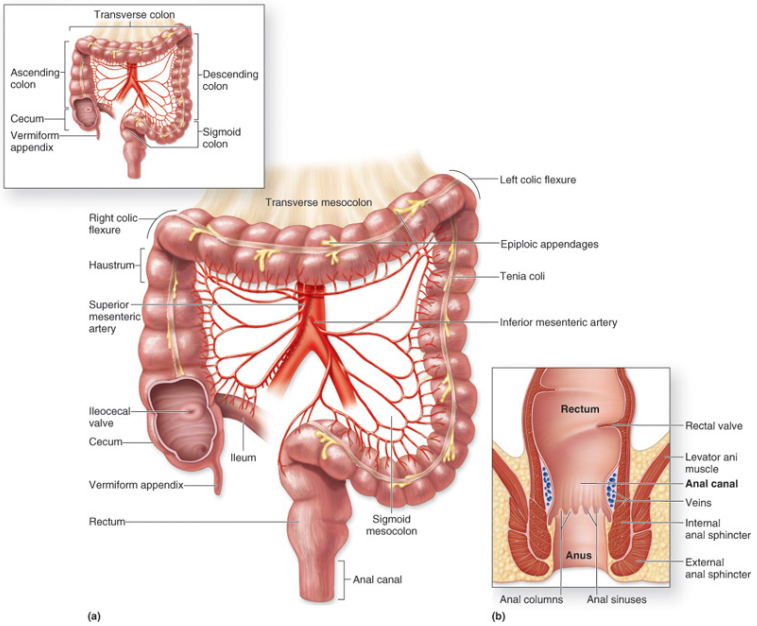


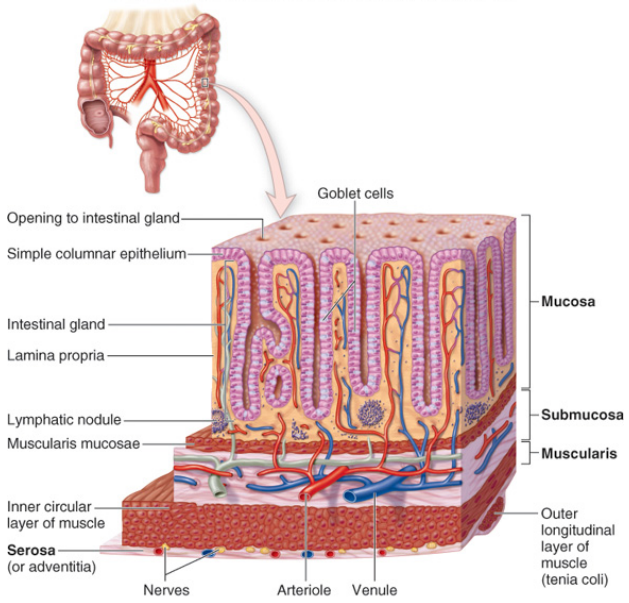




Large Intestine

- approximate length of 1.5 meters (5 feet)
- diameter of 6.5 centimeters (2.5 inches).
- Absorbs most of the water and electrolytes from the remaining digested material.
- Watery material that first enters the large intestine soon solidifies and becomes feces.
- Stores fecal material until the body is ready to defecate.
- Absorbs a very small percentage of nutrients still remaining in the digested material.
- Composed of four segments:
  - the cecum, colon, rectum, anal canal





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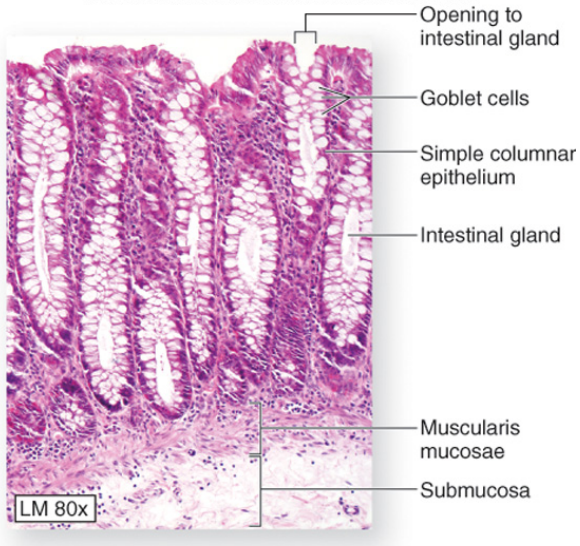


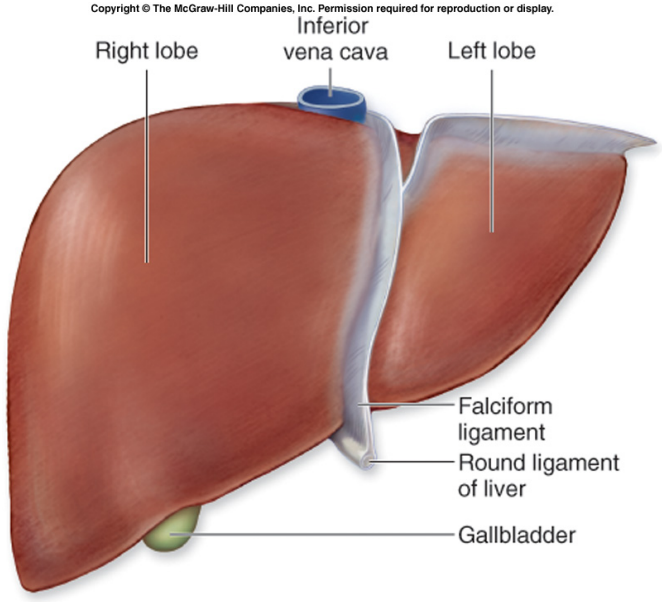
(b)

Accessory Digestive Organs

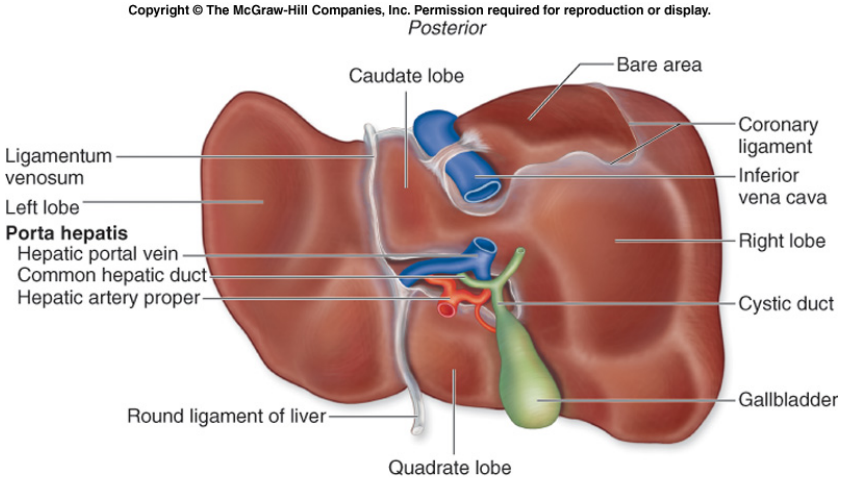
- **The liver**
  - composed of four incompletely separated lobes
  - supported by two ligaments
- Right lobe
- Left lobe
- Falciform ligament
- Round ligament
- Caudate lobe
- Quadrate lobe

Functions of The Liver

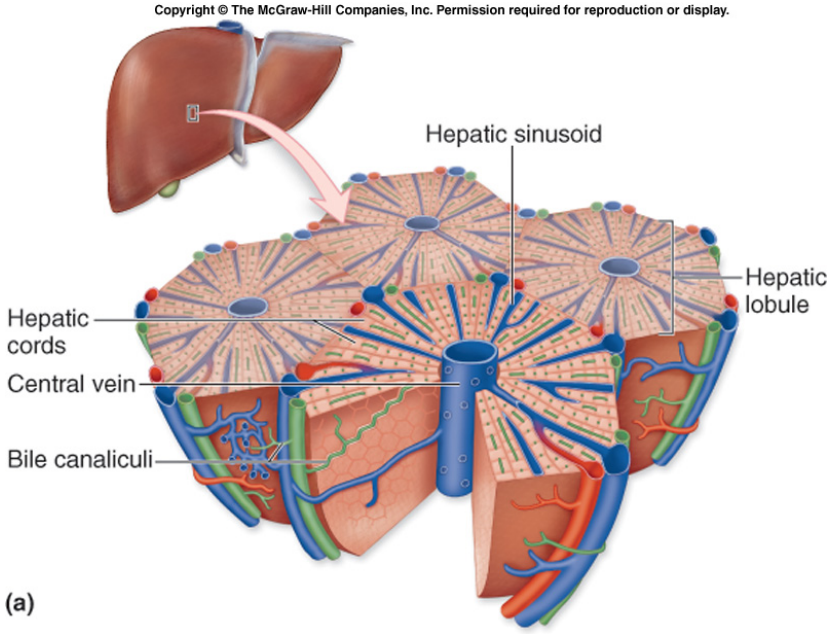
- Produce bile.
  - a greenish fluid that breaks down fats into small droplets to assist in their chemical digestion
- Detoxify drugs, metabolites, and poisons.
- Store excess nutrients and vitamins and release them when they are needed.
- Synthesize blood plasma proteins such as albumins, globulins, and proteins required for blood clotting.
- Phagocytize debris in the blood.
- Help break down and recycle components of aged erythrocytes and damaged or worn-out formed elements.



(a) Anterior view



(b) Posteroinferior view



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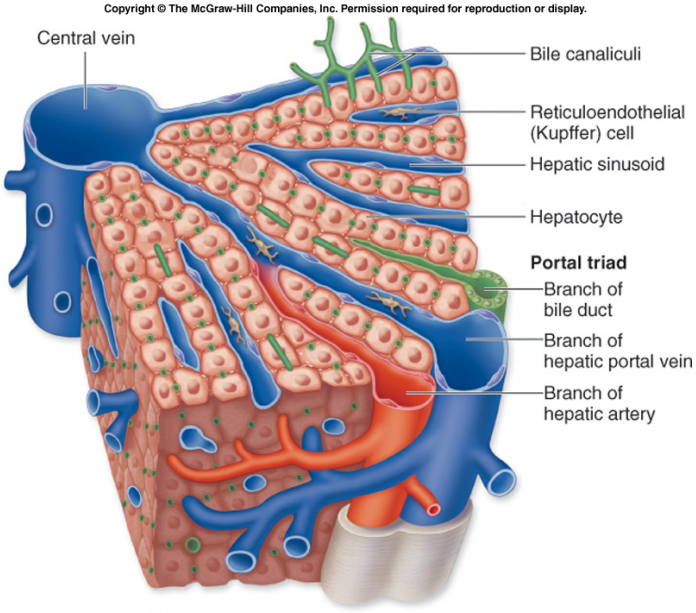

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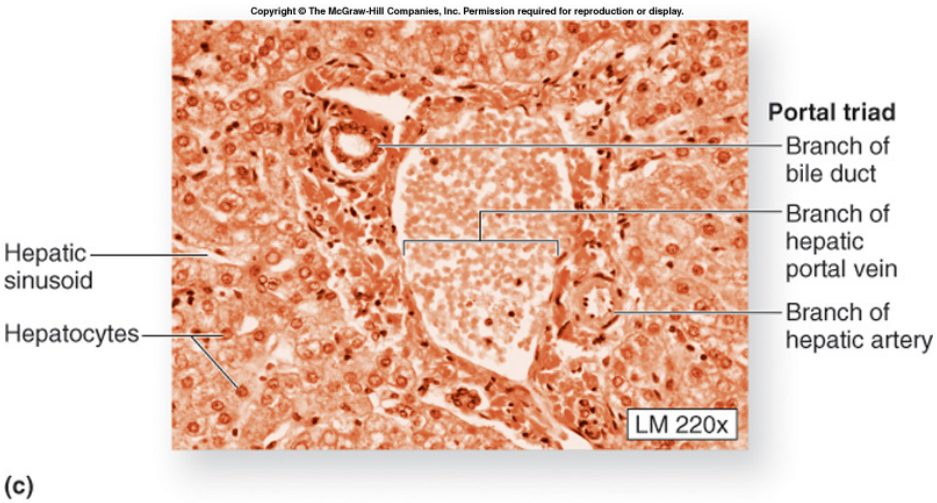
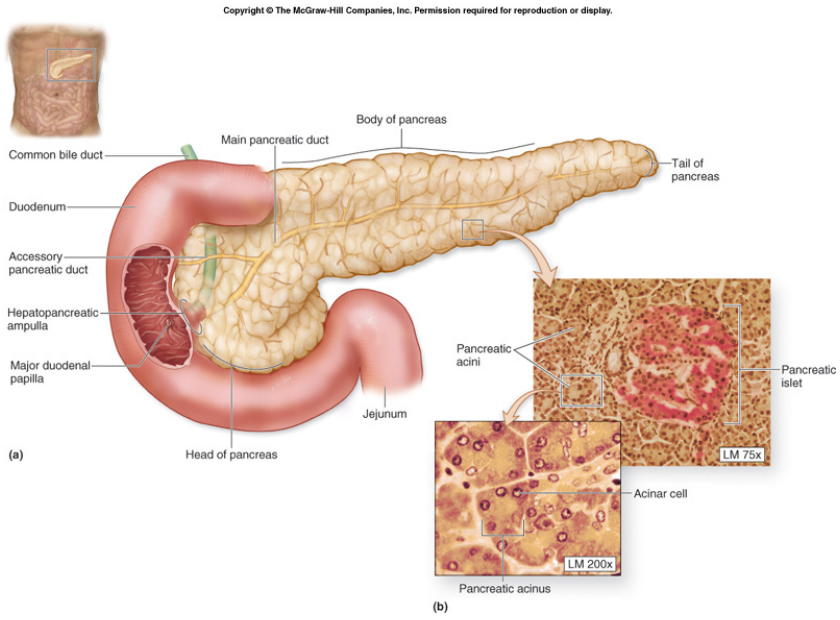


Accessory Digestive Organs

- **Gallbladder**
  - concentrates bile produced by the liver and stores this concentrate until it is needed for digestion
  - cystic duct connects the gallbladder to the common bile duct
  - can hold approximately 40 to 60 milliliters of concentrated bile

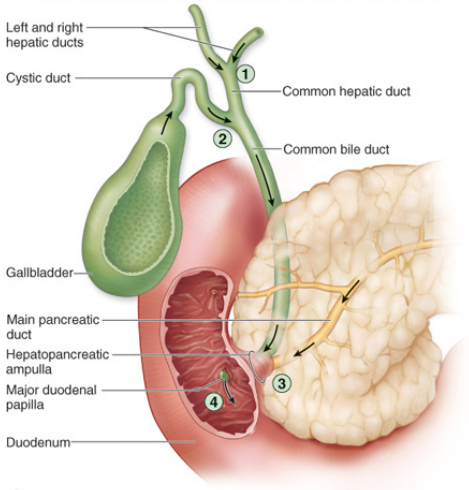
Accessory Digestive Organs

- **Pancreas**
  - mixed gland because it exhibits both endocrine and exocrine functions
- Endocrine functions are performed by the pancreatic islets.
- Exocrine activity results in the secretion of digestive enzymes, collectively called pancreatic juice, into the duodenum.



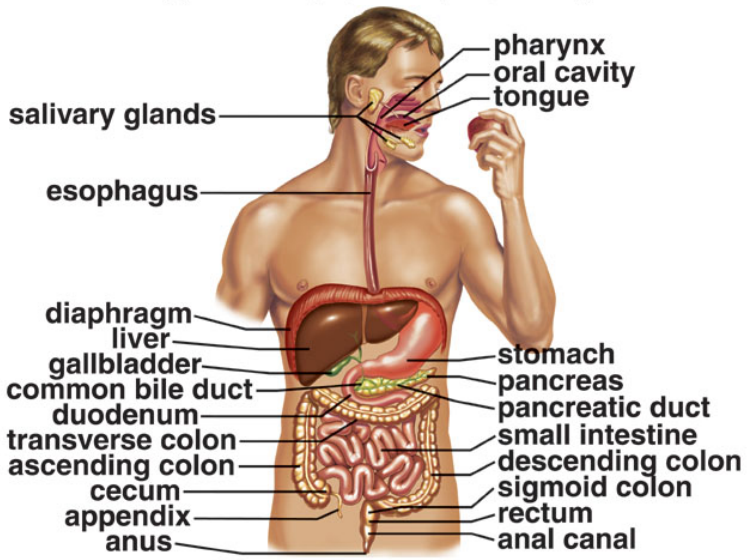
Accessory Digestive Organs

- The biliary apparatus.
  - network of thin ducts that carry bile from the liver and gallbladder to the duodenum
  - the left and right lobes of the liver drain bile into the left and right hepatic ducts, respectively
  - the left and right hepatic ducts merge to form a single common hepatic duct
  - the cystic duct attaches to the common hepatic duct and carries bile to and from the gallbladder



1. Left and right hepatic ducts merge to form a common hepatic duct.
2. Common hepatic and cystic ducts merge to form a common bile duct.
3. Pancreatic duct merges with common bile duct at the hepatopancreatic ampulla.
4. Bile and pancreatic juices enter duodenum at the major duodenal papilla.

Digestive system



- From mouth to stomach

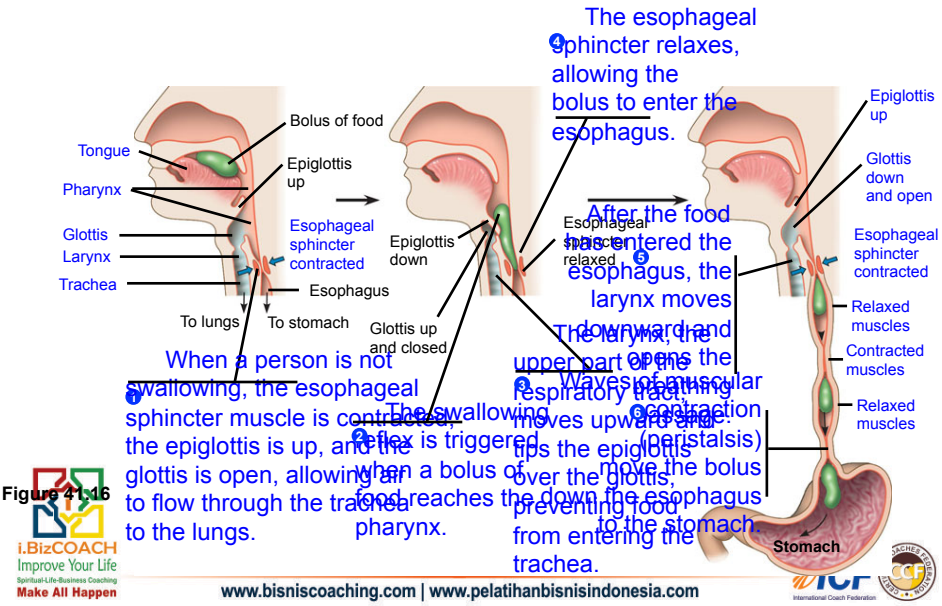
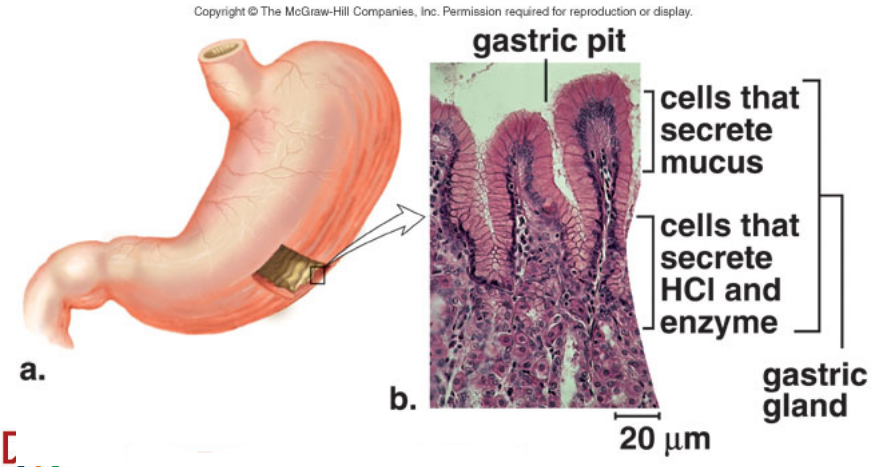
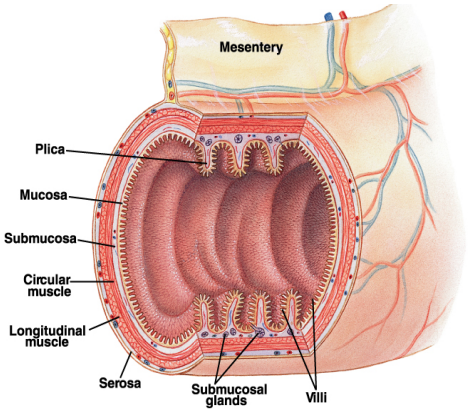


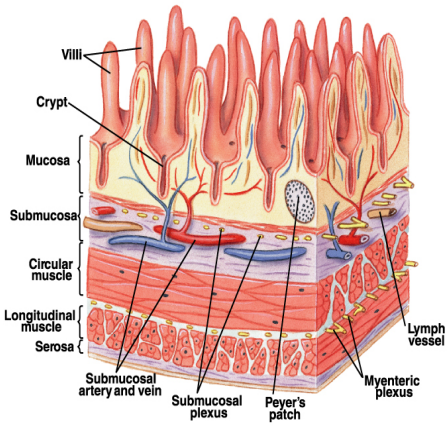
Figure 41.16

Anatomy and histology of the stomach



Structure of small intestine

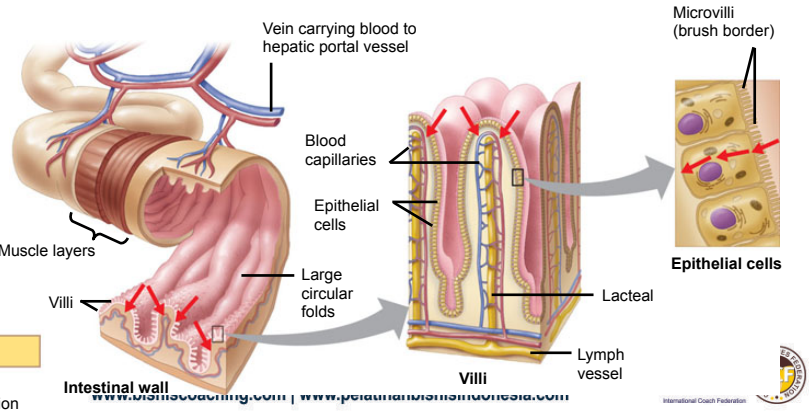




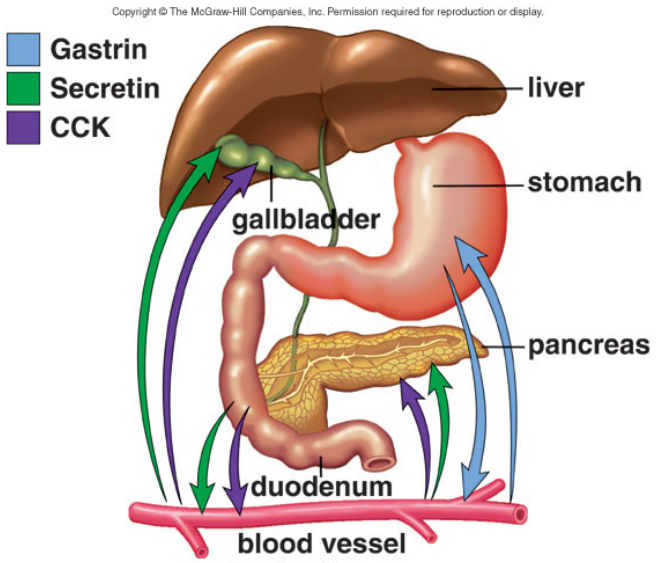
Absorption of Nutrients

- The **small intestine** has a huge surface area
- **villi** and **microvilli**

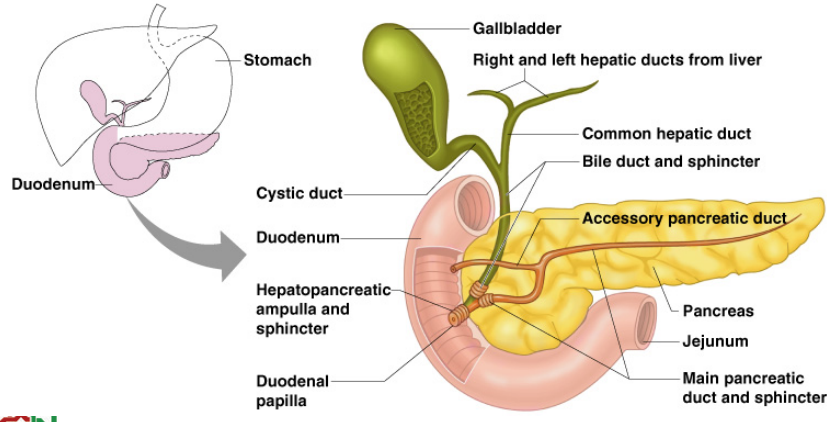
Figure 41.23



Hormonal control of digestive gland secretions

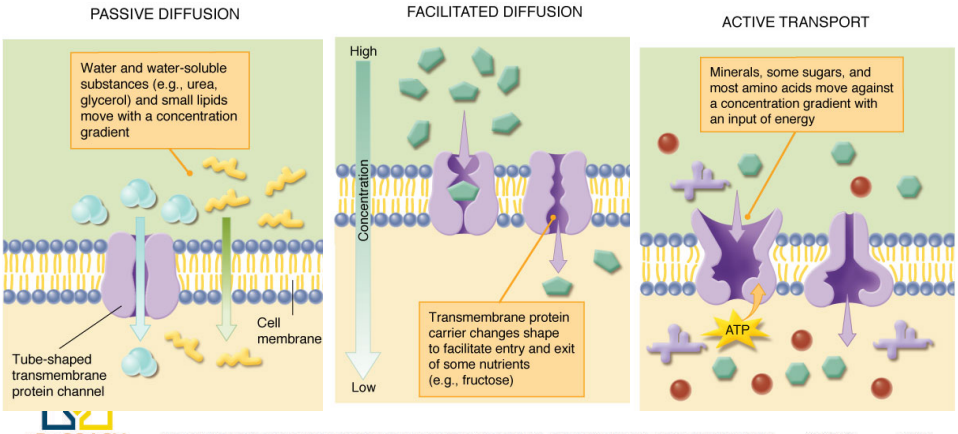


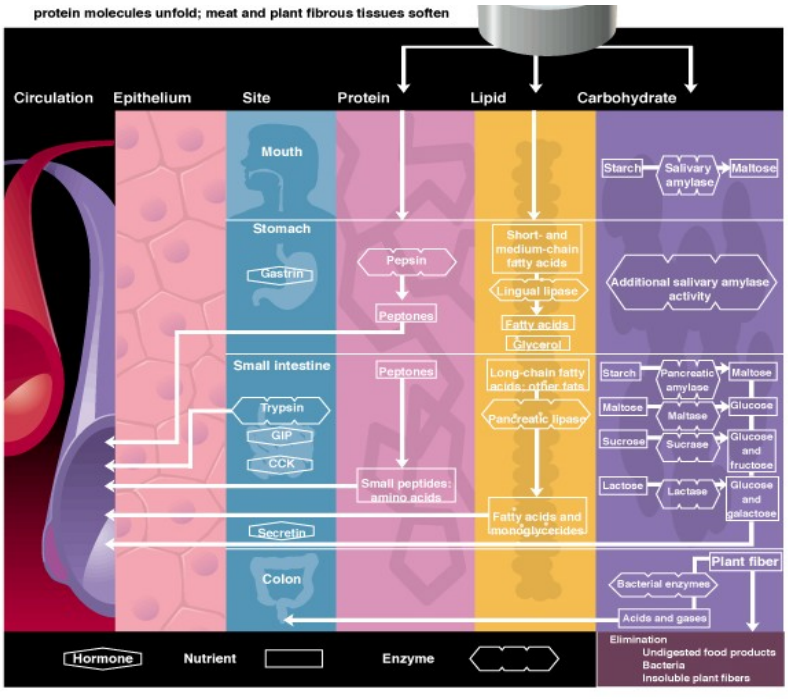
Chemical Digestion in the Small Intestine



Overview of Absorption

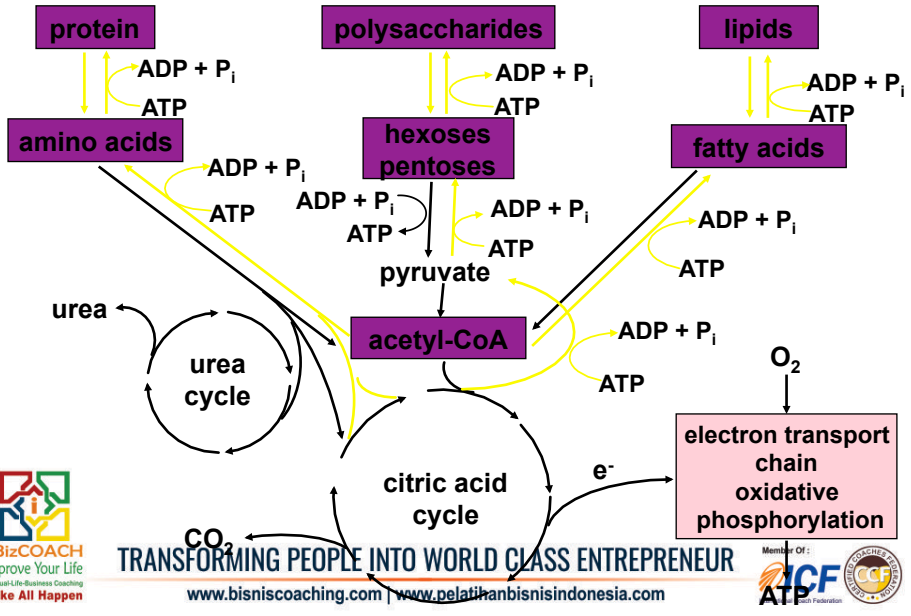
- **Absorptive mechanisms**
  - **Passive diffusion • Facilitated diffusion • Active transport**



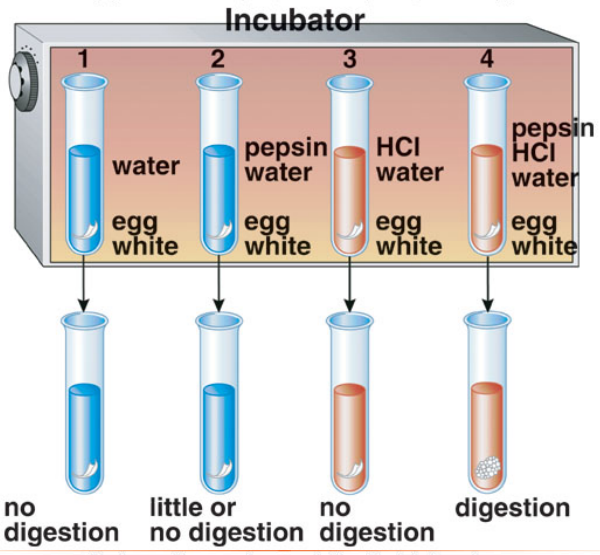


	(a) Carbohydrate digestion	(b) Protein digestion	(c) Nucleic acid digestion	(d) Fat digestion
ORAL CAVITY, PHARYNX, ESOPHAGUS	Polysaccharides (starch, glycogen) ↓ SALIVARY AMYLASE Smaller polysaccharides, maltose			
STOMACH		Proteins ↓ PEPSIN Small polypeptides		
LUMEN OF SMALL INTESTINE	Polysaccharides ↓ PANCREATIC AMYLASES Maltose and other disaccharides	Polypeptides ↓ TRYPSIN, CHYMOTRYPSIN Smaller polypeptides ↓ AMINOPEPTIDASE, CARBOXYPEPTIDASE Amino acids	DNA, RNA ↓ NUCLEASES Nucleotides	Fat globules ↓ BILE SALTS Fat droplets (emulsified) ↓ LIPASE Glycerol, fatty acids, glycerides
EPITHELIUM OF SMALL INTESTINE (BRUSH BORDER)	↓ DISACCHARIDASE Monosaccharides	Small peptides ↓ DIPEPTIDASES Amino acids	↓ NUCLEOTIDASES Nucleosides ↓ NUCLEOSIDASES Nitrogenous bases, sugars, phosphates	

Overview of Metabolism



Digestion experiment



Carbohydrates

- *Complex carbohydrates* from foods like breads and pasta can be converted to glucose and used rapidly.
- Body cells can utilize fatty acids as an energy source, but brain cells require glucose, thus carbohydrates are an essential part of the diet.
- Complex, rather than simple, carbohydrates should make up the bulk of the diet.

- *Simple carbohydrates* like table sugar (sucrose) contribute to energy needs and weight gain without supplying other nutrients.
- *Insoluble fiber* helps regularity and may help prevent cancer by limiting the time substances are in contact with the intestinal wall.
- *Soluble fiber* combines with bile acids and cholesterol in the intestine and prevents them from being absorbed.

Complex carbohydrates

Proteins

- Meat, milk or eggs are complete proteins; they provide all 20 *essential amino acids*.
- Because individual vegetables do not provide all essential amino acids, vegetarians must be careful to consume a combination of legumes, grains, vegetables, seeds and nuts to secure *complementary proteins*.
- The amino acid pool relies on continual uptake; amino acids are not stored.

Lipids

- Fat and cholesterol are *lipids*.
- Lipids, found in fats and oils, should be used sparingly.
- Current guidelines suggest that fat should account for 30% or less of daily calories.
- *High-density lipoproteins* (HDL) carry cholesterol to the liver and is considered to be “good”.

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- *Low density lipoprotein* (LDL) takes cholesterol to the cells and may contribute to the development of plaque on blood vessels walls; it is considered to be "bad".
- *Saturated fatty acids* lack double bonds and raise LDL cholesterol levels.
- *Linoleic acid* and *linolenic acid* are two *essential fatty acids* the body cannot make; *polyunsaturated fats* supply these.

Vitamins

- *Vitamins* are organic compounds that the body cannot produce but needs for metabolic purposes; some are portions of *coenzymes*.
- Vitamins A, E, and C are *antioxidants* that protect cell contents from damage due to *free radicals.*
- Free radicals donate an electron to DNA, proteins, enzymes, membranes, etc. and can damage cell structures or cause cancer.

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- *Vitamin D*
- A precursor molecule in skin is converted to vitamin D after exposure to ultraviolet (UV) light.
- Vitamin D is modified first in the kidneys and then the liver until it becomes *calcitriol*, which is needed for calcium absorption in intestines.
- In the U.S., milk is often fortified by vitamin D.
- Vitamin D is a *fat-soluble* vitamin.

Minerals

- The body contains more than 5 grams of each *major minerals* and less than 5 grams of each *trace minerals*.
- *Calcium* and *phosphorus* are in bones and teeth.
- *Potassium* and *sodium* are involved in nerve conduction.
- Trace minerals are critical in various enzymes and hormones.

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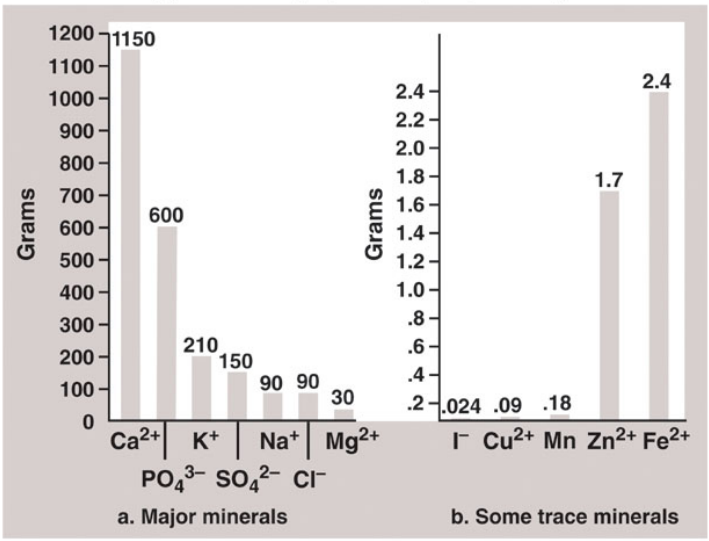
Minerals in the body



- *Calcium*
- Calcium is needed to have strong bones.
- Older women in particular are at risk for *osteoporosis*, a degenerative bone disease due to insufficient intake of calcium because bone cells are constantly building and eroding bone tissue.
- Calcium supplement with vitamin D (and also estrogen for women) can help prevent this bone loss.

- *Sodium*
- Most Americans have too much salt in their diet.
- High sodium intake is linked to *hypertension* in some persons.
- About one-third of the sodium we consume occurs naturally in foods; another one-third is added during commercial processing; and the final one-third is added during cooking or at the table in the form of table salt.

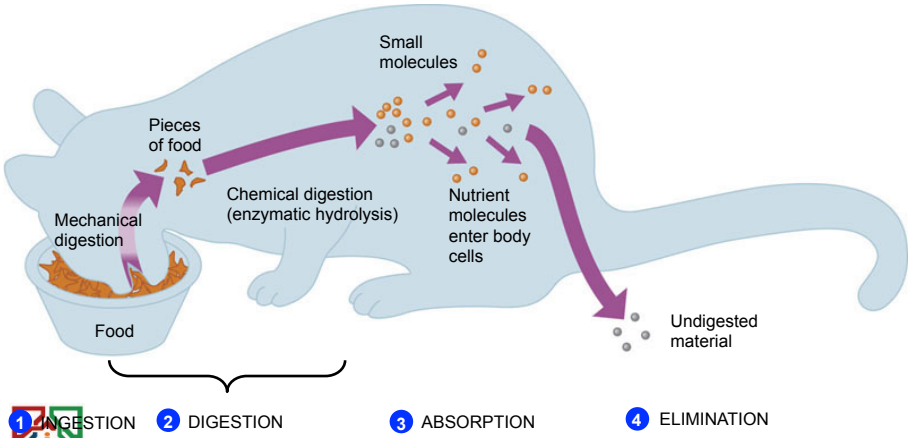
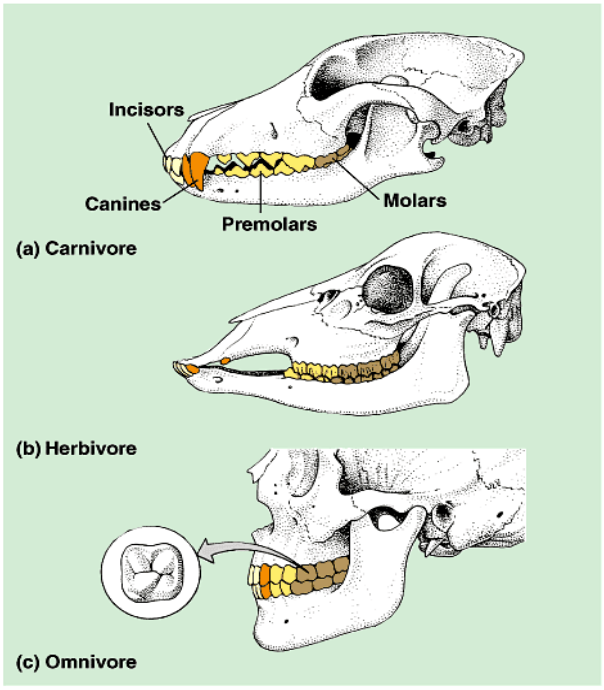


Figure 41.12



Structural Adaptations of Teeth in Mammals

Two Main Systems

- Monogastric/ Non-ruminant
  - animals that have simple, one compartment stomachs
- Ruminant
  - animals that have a stomach divided into several parts

Ruminant Animals

- Have multiple compartment stomachs
- Utilizes large amounts of roughage
- “Cud” chewers
- Includes animals such as: goats, cattle, sheep
- Bacteria in the digestive system breaks down cellulose into useable energy

Ruminant Animals

- Ruminant – herbivores possessing multiple digestive tract compartments for feed breakdown before feed reaches the “true” stomach
  - True ruminants - cattle, sheep, goats
  - Pseudo-ruminants - camels

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Parts of the Digestive System

- Stomach
  - two types of systems
    - monogastric/ non-ruminants
    - ruminants

Ruminant Stomach

- 4 compartments
  - Rumen
  - Reticulum
  - Omasum
  - Abomasum

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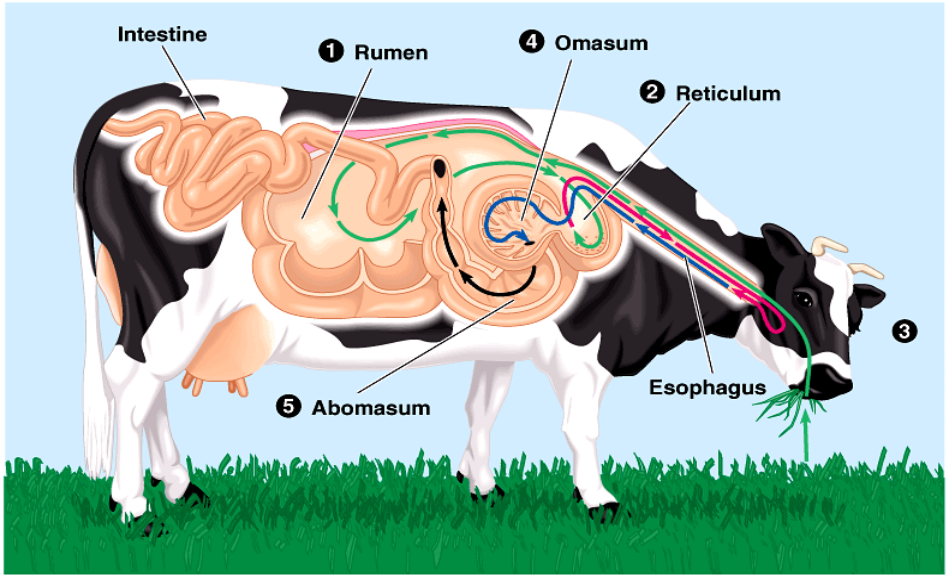
Ruminant Digestion: assisted by microbes in four-chambered stomach



Ruminant Stomach

- Reticulum
  - honeycomb shape
  - traps foreign material
  - stores, sorts, and moves food back up for regurgitation or into the rumen for digestion
  - young ruminants have an esophageal grove (a muscular fold) that allows milk to go directly to the omasum

Ruminant Stomach

- Rumen
  - food is soaked, mixed, and fermented by bacteria
    - symbiotic relationship between bacteria and the rumen
  - carbohydrates are broken down into starches and sugars
  - fatty acids are absorbed through the wall of the rumen
  - bacteria also used nitrogen to form amino acids

Ruminant Stomach

- Omasum
  - has many plies
  - grinds roughage
  - removes most of water
- Abomasum
  - further breakdown of food by contraction and relaxation of muscles
  - food is pressed together, massaged and mixed with digestive juices

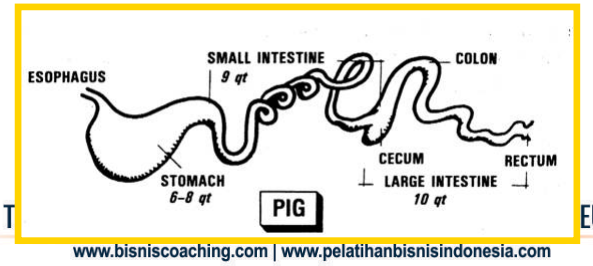
Ruminant Digestion

Mammalian Digestive Systems

- **Monogastric**
- **Equine**
- **Ruminant**

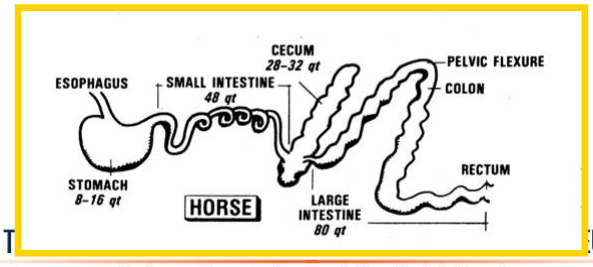
Monogastric (Simple Stomach)

- Humans, pigs, predators
- One compartment
- Glandular design



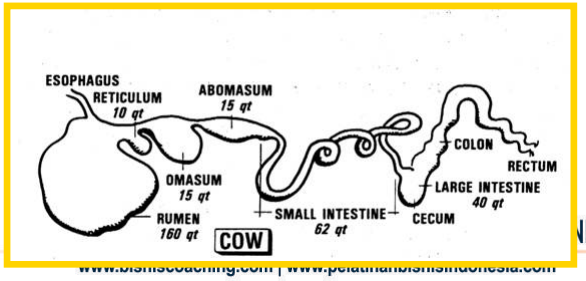
Equine

- Horses and their relatives
- One glandular compartment
- Hind-gut fermenter (cecum) to digest plants



Ruminant

- Most herbivores
- Four <u>compartment</u> stomach
- Fore-gut fermentation vat to digest plants



The Ruminant

Nature's Amazing Plant-Digesting Machine

Ruminant Facts (Bovine)

I thought Dumbo was an elephant

- Chews cud
- 40,000-60,000 jaw movements/day
- No upper incisors - dental pad
- Does not "bite" grass - wraps tongue
- Uses fermentation to digest plants
- Symbiotic relationship with bacteria
- Produces 13 gallons of gas/hour
- Produces 40 liters of saliva/day
- Does not sleep!

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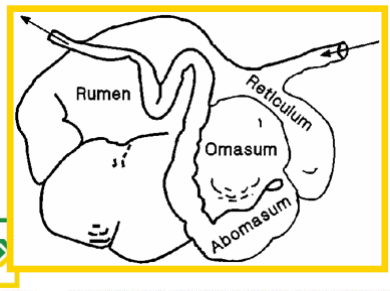
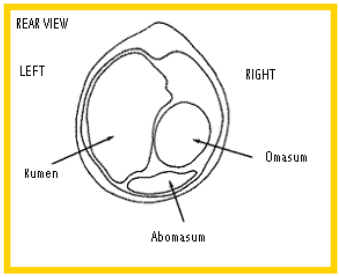
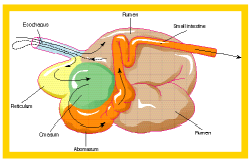
Stomach Compartments

- Rumen - fermentation vat
- Reticulum - rumen's "assistant"
- Omasum - dehydrator
- Abomasum - glandular stomach



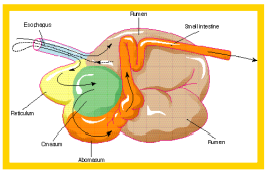




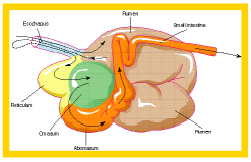
Rumen

- Largest compartment
- On left side of animal
- Contains micro-organisms
- Ferments cellulose
- Divided into chambers
- Continually contracting
- Contains papillae
- pH close to neutral (6 - 7)

Reticulum



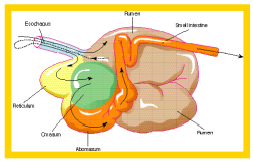
- Smallest compartment
- Lies close to the heart
- Small sac - part of rumen body
- Catches dense, heavy feed for later rumination
- Contracts for regurgitation
- "Honeycomb" lining
- Catches hardware and stores it



Omasum

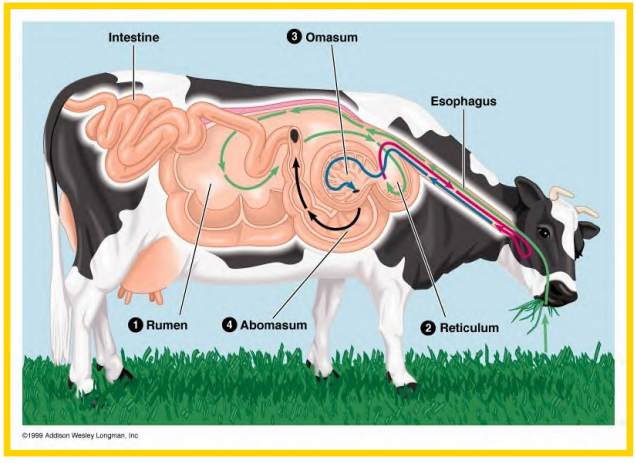
- Third compartment
- Globe-shaped
- Lining called "many plies"
- Reduces feed particle size
- Absorbs water and dries out ingesta
- Absorbs volatile fatty acids

Abomasum



- Final compartment
- Tubular in design
- "True" stomach (glandular)
- Secretes HCl and enzymes for chemical digestion
- Reduces pH to 2.5
  - Dissolves minerals
  - Kills rumen bacteria
  - Breaks down proteins
- Passes ingesta to small intestine

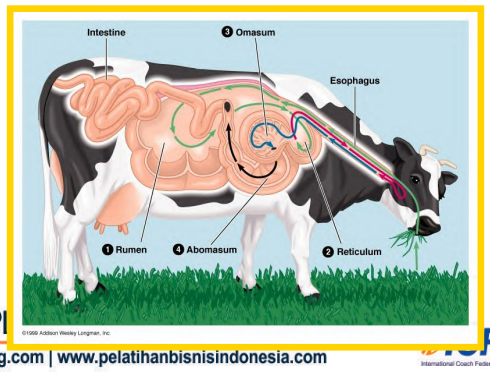
Ruminant Digestion



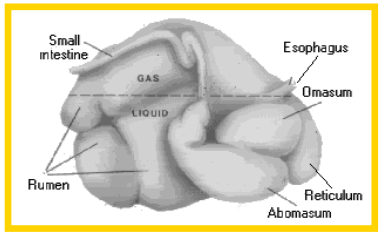
Ruminant Digestion

- Intake
- Mastication (chewing)
- Swallowing
- Regurgitation
- Remastication
- Fermentation
- Eructation
- Absorption
- Digestion

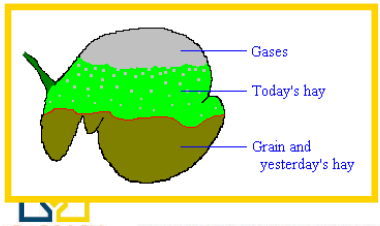
Rumination



Fermentation



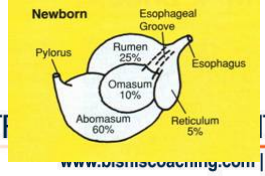
- Anaerobic bacteria break down cellulose
- VFA's released by bacteria passed to bloodstream through papillae
- Ingesta passed to omasum by contractions



Calf Digestive Tract Development

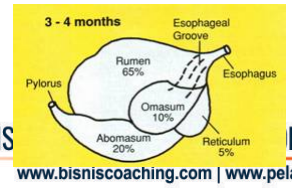
Calf Digestive Tract Development

- Only abomasum is functional
- Sucking action forms esophageal groove
- Milk passes directly to abomasum
- Milk curdles and digests slowly
- Rumen does not develop as long as calf is on milk only



Calf Digestive Tract Development

- Feed (grain) consumption causes rumen to develop
- Rumen is populated with micro-organisms from environment
- Bacteria produce VFA's which cause rumen to develop papillae and increase in size
- Calf can digest hay and grass once rumen develops



Rumen Exploration

Agriscience Lab

The Cannula

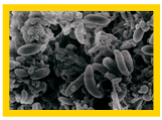
- Provides direct access to the rumen
- Possible only in ruminants
- Rumen wall is very close to epidermis behind the ribs on the left side
- Surgically inserted by a veterinarian
- Not painful or dangerous to the cow
- Permits researchers to:
  - Observe rumen function
  - Evaluate digestion of different feedstuffs
  - Remove fluid to use as inoculant for sick cows

Rumen Investigation and Sampling

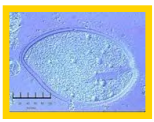
- Put on obstetrical glove
- Remove cannula lid and permit gas to exit
- Feel rumen wall and papillae
- Reach into ingesta
- Pick up ingesta (liquid and solid)
- Collect a fluid sample

Rumen Fluid Evaluation

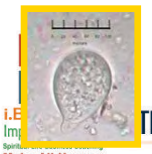
The Rumen Contains:



- Bacteria (digest cellulose)
  - Over 200 species
  - Smaller than 5 microns (5/1000 mm)
  - Can only be seen with an electron microscope



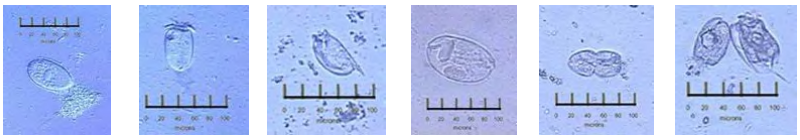
- Protozoa (control bacteria population)
  - Much larger (20-200 microns)
  - Can be seen with microscope at 400X
  - Prey on bacteria



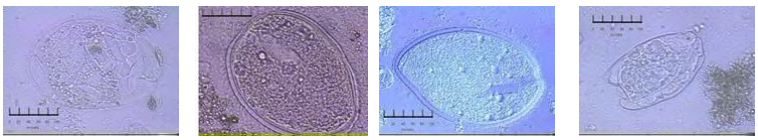
- Fungi (aid in cellulose digestion)
  - Same size range as protozoa
  - Numbers are very low in rumen
  - Discovered only 20 years ago

Rumen Microorganisms

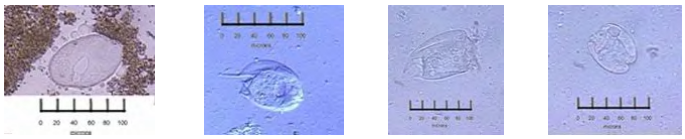
Dasytrich and Entodinium protozoa



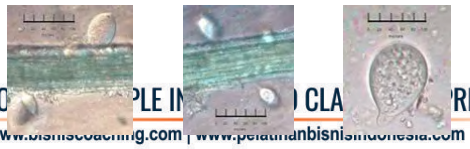
Large protozoa



Isotrich and Entodinium protozoa



Fungal sporangia



Monogastric Animals

- Single, simple stomach structure
- Mostly carnivores and omnivores
  - Very simple - mink, cat and dog
  - Cecal digestion - horse, rabbit, elephant or rat
  - Sacculated stomach - kangaroo

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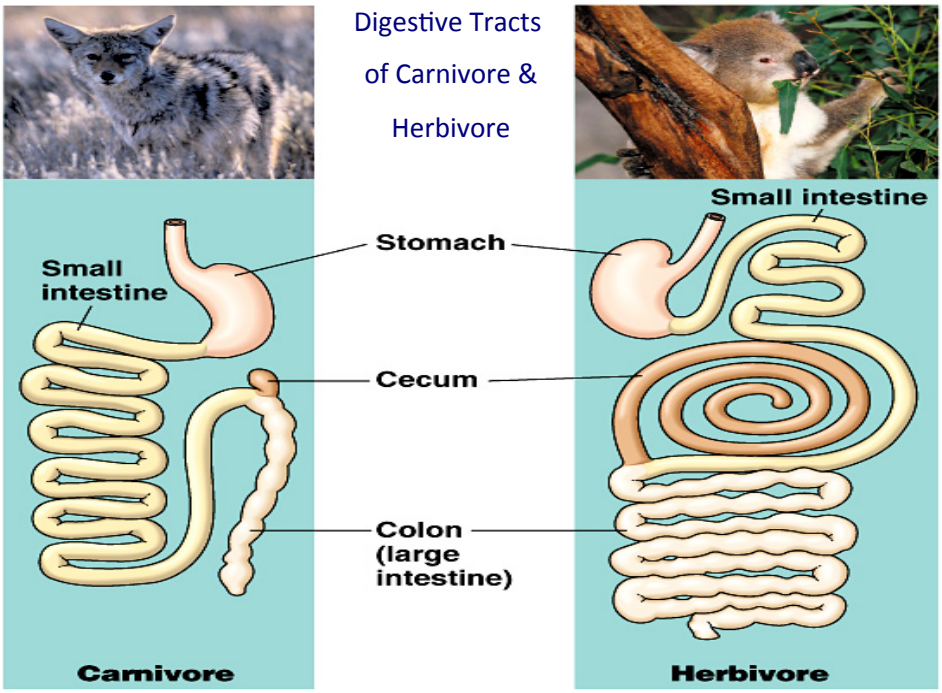
Monogastric/ Non-ruminants

- One compartment stomachs
- Need high energy, low fiber feeds (concentrates)
- Cannot digest high fiber feeds (roughage) very efficiently
- Animals such as pigs, horses, poultry
  - pig can only digest 22 % of roughage
  - horses can digest up to 39 % of roughage

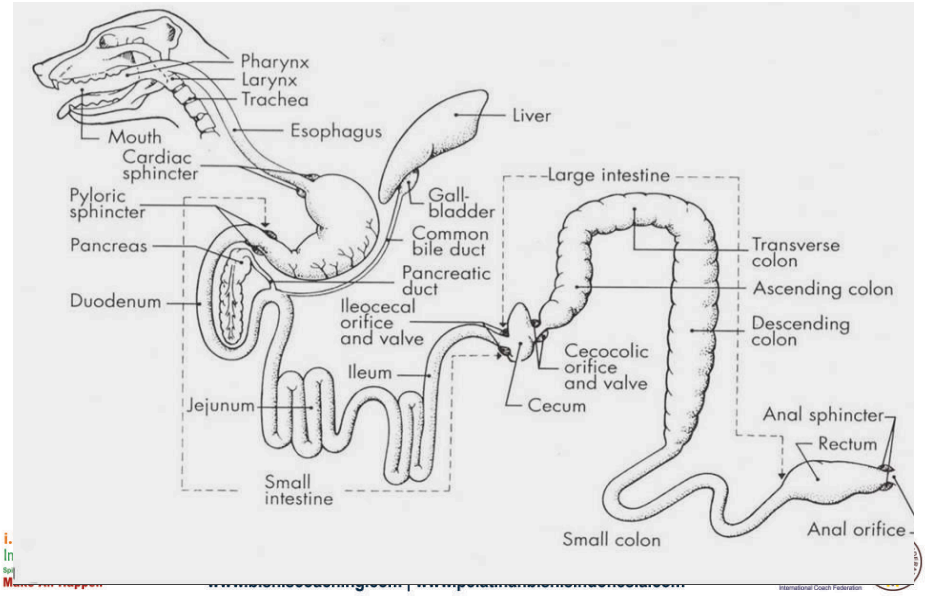
Non-Ruminant Stomach

- Further breakdown of food by contraction and relaxation of muscle
- Food is pressed together, massaged, and mixed with digestive juices
  - Hydrochloric acid begins to dissolve food
  - Pepsin breaks down proteins into amino acids
  - Rennin curdle casein (protein) in milk
  - Gastric Lipase breaks down fats into fatty acids.

Digestive Tracts of Carnivore & Herbivore



Dog digestive tract



Nutrition

- Provide animals with nutrients to enable them to:

- Optimize health, feed efficiency and profits
- The digestive system is a portal for nutrients to gain access to the circulatory system
  - Food is broken down to very simple molecules such as sugars, amino acids, fatty acids, etc… that are then transported across the GI tract lining into blood

Digestive anatomy and physiology

- Carnivore – Almost entirely on meat for food
  - Dog, Cats
- Herbivore - Depends entirely on plant food
  - Horses, Rabbits, Cattle, Sheep and Goats
- Omnivore – Both meat and plants for food
  - Swine, Chickens, Humans

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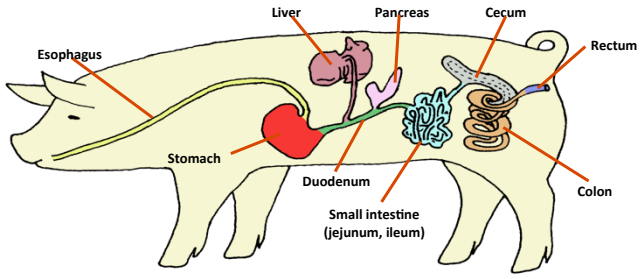
Animal Digestive Systems

- Monogastrics – Major Category:
  1. Simple Stomach – Pigs, Humans, Dogs
  2. Avian – Chickens, Turkeys
  3. Pseudo Ruminants (Hund gut [caudal] fermentors) – Horses, Rabbits
     - ❖ Simple stomach, but very large and complex large intestine
- Ruminants – Cattle, Sheep, Goats
  (Will by covered by Drs. Russell and Schoonmaker)

Affects nature of digestive processes and the kind of feed that can be utilized by the animal

Pig digestive tract



Adopted from Sisson 1975; Shumaker et al., 1979; Moran 1982)

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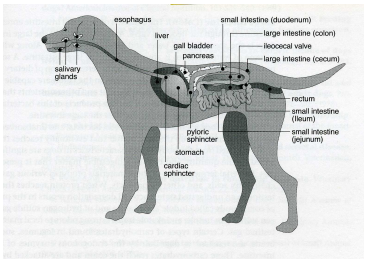
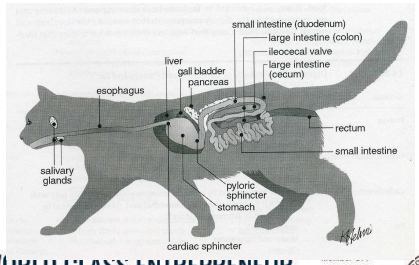
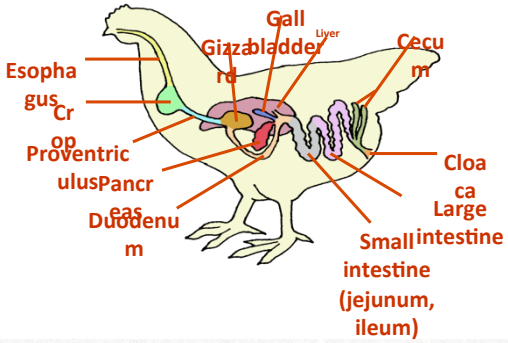
Dog and Cat digestive tract

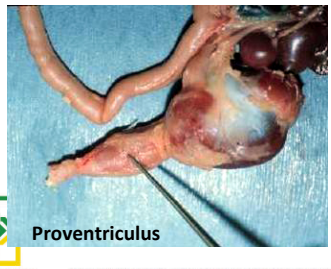




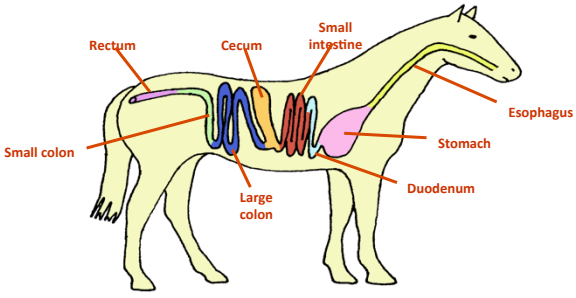
Poultry digestive tract



Specialized Poultry Organs



Horse digestive tract



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Organs and Structures of the Digestive System

- Mouth
- Esophagus
- Stomach
- Liver
- Pancreas
- Small intestine
- Large intestine

Mouth

- Mechanical breakdown of foodstuffs
  - chewing
  - reduces particle size
  - increases surface area for action of enzymes
- Saliva
  - Made of water with ~1% of it being mucus, electrolytes and enzymes
  - Lubricant
  - Contains amylase to begin starch digestion in some species

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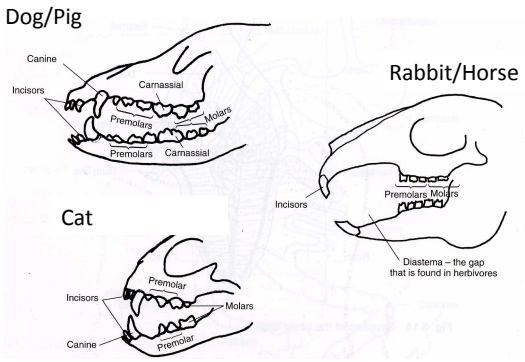
Skull & Dentition Variation



Esophagus

- Short muscular tube leading from the mouth to the stomach
- Moves food down the GI tract by peristaltic waves
  - Controlled by striated muscles (voluntary), smooth muscle (involuntary) and cholinergic nerves
  - Takes only a few seconds

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Stomach

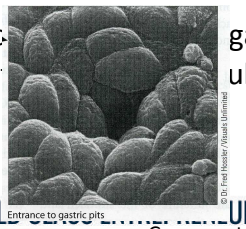
- Initial digestion of food, broken to smaller particles
  - Foodstuffs reduced to liquid form
  - Enzymatic and chemical digestion of proteins begins
- Four main regions
  - Cardia
    - Below the gastroesophageal sphincter
    - Receives swallowed food from the esophagus
  - Fundus
    - Adjacent or lateral to the cardia
  - Body
    - Large central region of the stomach
    - Main site of gastic juice production
  - Antrum (distal pyloric)
    - Grinds and mixes food with gastric juice
    - Provides peristalsis for gastric emptying

Stomach cont…

- Gastric juices
  - Hydrochloric acid (HCl) breaking of bonds
  - Proteases – proteins to polypeptides
    - Pepsin A
    - Pepsin B
    - Gastricsin
    - Chymosin
- These proteases all secreted as zymogens that require a pH-dependent conformational change for their conversion into active enzymes

Stomach cont…

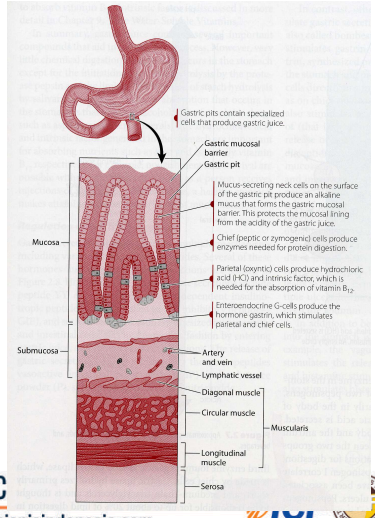
- Gastric Pits
  - Contain specialized cells that produce gastric juice
  - Gastric juice (~pH 2)
    - Produced by three func- gastric glands found in the gas ubmucosa of the stomach



Gropper et al., 2005

Stomach cont…

- Gastric Pits cont…
  - Several cell types secrete different substances within the pit
  - Neck (mucus) cells
    - Junction of stomach and esophagus
  - Parietal (oxyntic) cells
    - Body of stomach
  - Chief (peptic/zymogenic) cells
  - Enteroendocrine cells



Gropper et al., 2005

Stomach cont…

- Gastric Gland and secretion
  - Influenced by the amount of protein in a meal, meal volume, hormones that indirectly affect the acidity of the stomach
    - Adrenocorticotropic hormone [ATCH] ↑ HCl production
    - Secretin ↓ HCl via the release suppression of gastrin

Liver

- Major role in digestive process is to provide bile salts to small intestine
  - Needed for digestion and absorption of fats
  - Bile
    - Stored in the gallbladder
    - Synthesized from cholesterol
  - The duodenum receives secretions from the gallbladder via the common duct
- Fat digestion products are absorbed in the first 100 cm of small intestine
- The primary and secondary bile acids are reabsorbed almost exclusively in the ileum returning to the liver by way of the portal circulation (98 to 99%)

Bile Acids

- Cholic acid is the bile acid found in the largest amount in bile
- Cholic acid and chenodeoxycholic acid are referred to as primary bile acids
- Bile acids are converted to either glycine or taurine conjugates
  - Glycocholate – 24%
  - Glycochenodeoxycholate – 24%
  - Taurocholate – 12%
  - Taurochenodeoxycholate – 12%
  - Glycodeoxycholate- 16%
  - Taurodeoxycholate – 8%
  - Various lithocholate – 4%

Pancreas

- Provides a potent mixture of digestive enzymes to the small intestine
  - Helps in digestion of fats, carbohydrates, and proteins
  - Neutralizes the acidity of the chyme (gut contents) entering the duodenum
  - The pancreas releases its secretions into the pancreatic duct which then join the common duct and the duodenum
  - Enzymes include proteases, carbohydrases, lipases and nucleases

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Pancreatic Enzymes

- Lipase
  - Fats to fatty acids and glycerol
- Trypsin
  - Polypeptides to peptides
- Chymotrypsin
  - Peptides to amino acids
- Amylase
  - Starch to disaccharides
- Sucrase, Maltase, etc.
  - Disaccharides to monosaccharides

Small Intestine

- Three sections – duodenum, jejunum, ileum
  - Site of final stages of chemical enzymatic digestion
  - Where almost all nutrients are absorbed
  - Consists of four major layers
    - Mucosa
    - Submucosa
    - Musclaris
    - Serosa

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Large Intestine

- 3 sections – Cecum, Colon, Rectum
- Site of water absorption
- Bacterial fermentation occurs (production and absorption of volatile fatty acids)
  - Somewhat limited in monogastrics
- Feces formed.

Large Intestine cont…

- Cecum/Large Intestine
  - Limited plant fiber digestion
  - Microbes present produce the enzyme cellulase
    - Breaks down cellulose (one type of plant fiber)
    - Very inefficient system in monogastrics (except horses)

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Specialized organs of Poultry

- Beak
  - No lips, no teeth, and no chewing
- Crop
  - Out-pocketing of the esophagus that provides storage for consumed food
  - Foodstuffs moistened and softened
  - Little digestion occurs

Specialized organs of Poultry cont…

- Proventriculus ("true stomach")
  - Glandular stomach where the first significant amount of digestive juices are added
- Gizzard
  - A muscular organ used to grind and break up food
  - May contain grit (small stones) eaten by animal
- Cloaca
  - Common chamber into which the digestive, urinary, and reproductive tracts open
  - When fecal material is excreted, the cloaca folds back at the vent allowing the rectal opening of the large intestine to push out, closing the reproductive tract opening

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Specialized organs of hindgut fermentors (Horses)

- The mouth to the small intestine have similar functions as compared to other monogastrics
- However
  - Large Intestine is a major difference between monogastrics and hind gut fermentors
  - Large intestine (Cecum) is exceptionally large and complex compared to monogastrics and ruminants

Specialized organs of hindgut fermentors (Horses)

- Cecum function
  - Microbes present break down the plant fiber
    - Produce energy to be absorbed through the cecum as VFAs
    - Synthesize more microbes, vitamins and amino acids
    - Less efficient than rumen since cecum is downstream of digestive organs (stomach and small intestine)

Digestive System Comparisons

Function	Monogastric	Hind Gut Fermentors
Digest and extract energy from cellulose	Very limited (large intestine)	Yes (large intestine)
Utilize dietary sugar sources directly	Yes	Yes
Utilize protein from feeds directly	Yes	Yes
Utilize fat from feeds directly	Yes	Yes
Utilize microbial protein	No	No

Monogastric Digestive System

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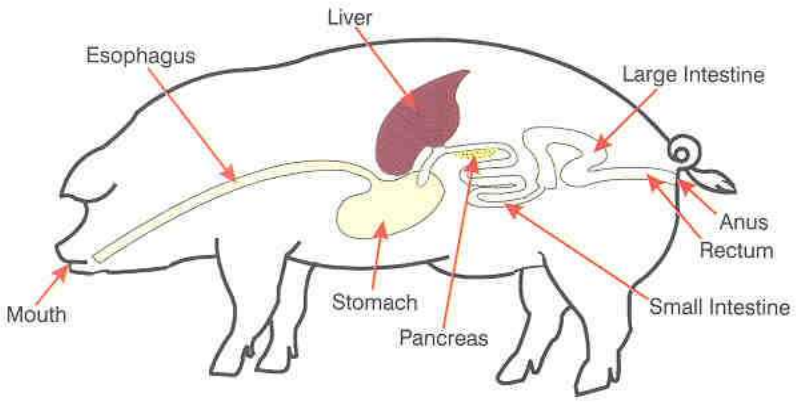
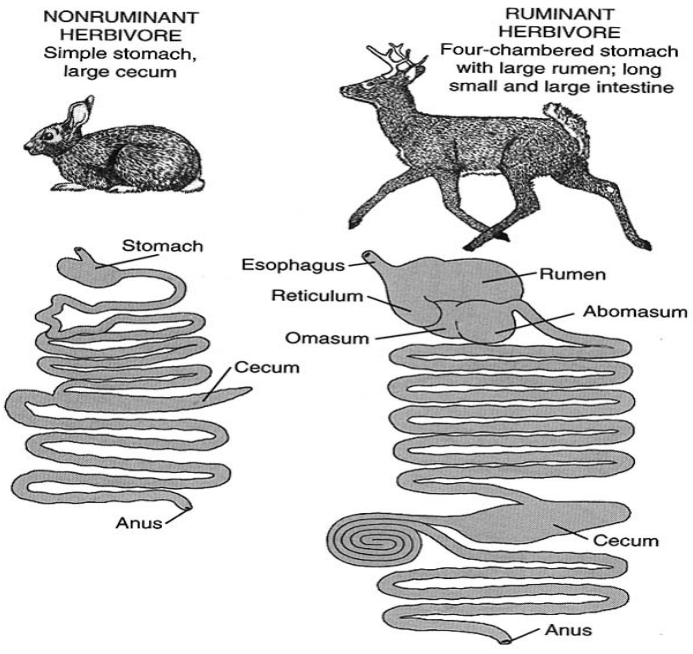
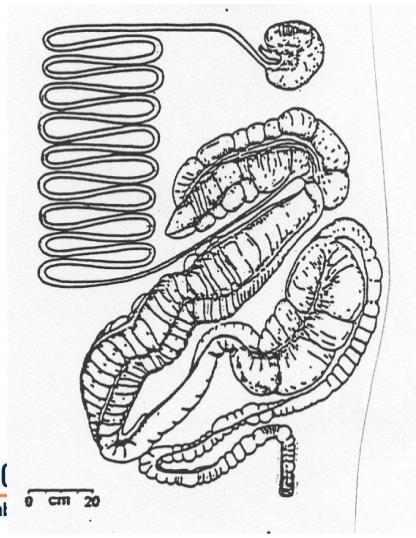
Monogastric System





GIT Classifications - Horse

- Monogastric herbivore with extensive post-gastric fermentation
  - Simple stomach incapable of utilization of forage-based (high fiber) diets
  - Extensive fermentation after primary sites of digestion and absorption



Parts of the Digestive System

- Cecum
  - located where small intestine joins large intestine
  - horses use the cecum to digest large amounts of fiber
  - not used by many other non-ruminants
  - microorganisms in the cecum breakdown roughage to make it available for use
  - not as efficient as the rumen

Matching…

Species
- Cow
- Pig
- Kangaroo
- Sheep
- Horse
- Dog
- Chicken

Digestive System
- Ruminant
- Monogastric
- Pre-gastric Fermentation
- Post-gastric Fermentation
- Herbivore
- Carnivore
- Omnivore

Answers

- Cow- Ruminant, Pre-gastric, Herbivore
- Pig- Monogastric, Post-gastric, Omnivore
- Kangaroo- Monogastric, Pre-gastric, Herbivore
- Sheep- Ruminant, Pre-gastric, Herbivore
- Horse- Monogastric, post-gastric, herbivore
- Dog- Monogastric, post-gastric, carnivore
- Chicken- Monogastric, Post-gastric, Omnivore

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Basic Organization

- Mouth
- Esophagus
- Stomach
- Small intestine
- Large intestine
- Anus

Associated Structures

- Pancreas
- Liver
- Gallbladder
- Salivary glands

} *Contribute to small intestinal digestion*

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Structures in Mouth

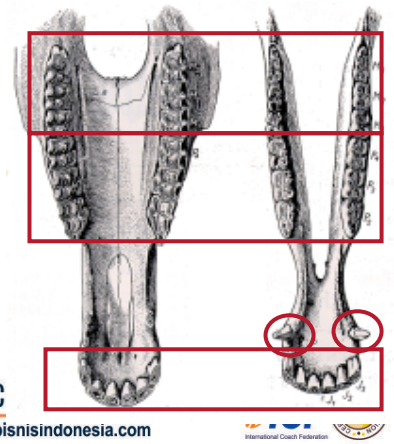
- Lips
- Teeth
- Tongue
- Salivary glands

Monogastric Teeth

- Function:
  - Mechanically reduce particle size
  - Increase surface area

Four types:

- Incisors are used for cutting
  - Canine (fangs, eye teeth, tusks) are tearing teeth
  - Premolars and molars (cheek teeth) grind the food



Monogastric Esophagus

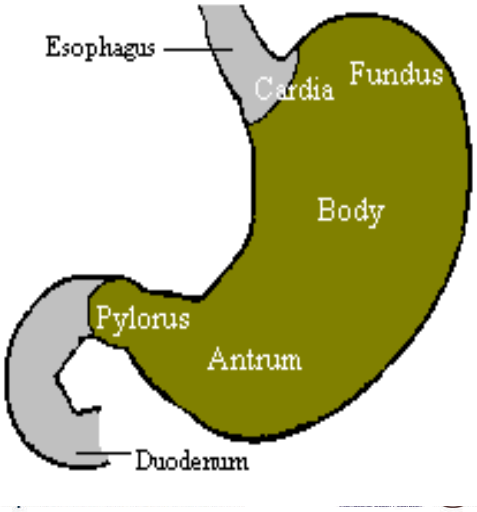
- Transport of food from mouth to stomach
- Uses peristaltic contractions (wave contractions)
- Horse/Pig:
  - Striated muscles for first 2/3
  - Smooth muscles for last 1/3
  - In horse, esophagus joins stomach at an oblique angle and cardiac sphincter (the valve between the stomach and esophagus) only allows one-way flow
    - MOST horses cannot belch out gas or vomit
- Dog:
  - Striated muscles throughout allow GREAT control of digesta movement both directions

Gastric Digestion

- Functions
  - Reservoir for controlled release of digesta to small intestine
    - Horse has small capacity – requires increased number of smaller sized meals
  - Mixing food
  - Mechanical breakdown of feed
  - Hydrolytic digestion by acid and enzymes
    - Mainly protein
  - Kill bacteria
  - Secrete intrinsic factor: needed for vitamin B_{12} absorption
  - Hormone production

Stomach Regions

- Esophageal
  - Non-glandular
- Cardiac
  - Secretes mucus
- Fundic
  - Parietal cells
  - Chief cells
- Pyloric
  - Mucus



Stomach Secretions

- HCl
  - Decreases pH (~2-3)
  - Denatures protein
  - Kills bacteria
  - Activates pepsinogen
- Mucus
  - Protects lining from acid and enzymes
    - No "autodigestion"
  - Lubricant
- Pepsinogen
  - Activated form is pepsin
  - Hydrolyzes protein
- Rennin (abomasum)
  - Clots milk
- Lipase
  - Some species

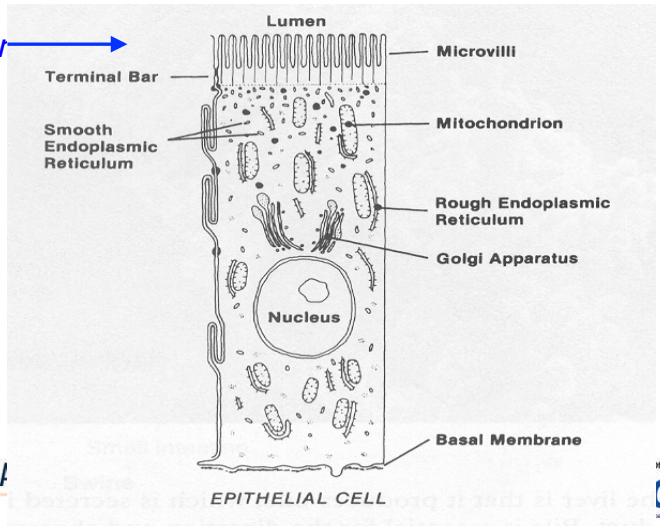
Small Intestine

- Composed of 3 segments (proximal to distal)
  - Duodenum
    - Releases bile and pancreatic secretions
    - Active site of digestion
  - Jejunum
    - Active site of nutrient absorption
  - Ileum
    - Active site of nutrient absorption
      - Most water, vitamins & minerals
    - Some bacterial presence
      - Fermentation

★ The pH of the small intestine increases towards 7.0 as food moves from the duodenum to the ileum

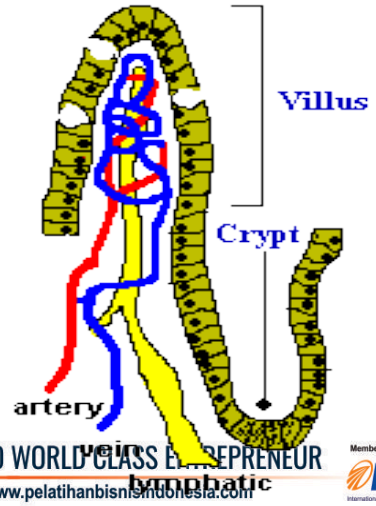
Intestinal Epithelial Cell

Brush border



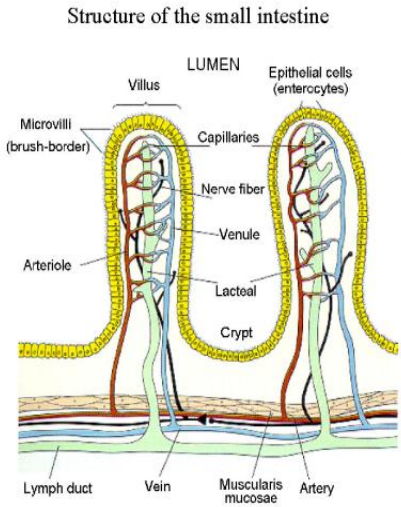
Small Intestine – Absorptive Surface

- Villi
- Enterocyte
- Brush border
- Cell migration from crypts to tips of villus
  - 2-3 days

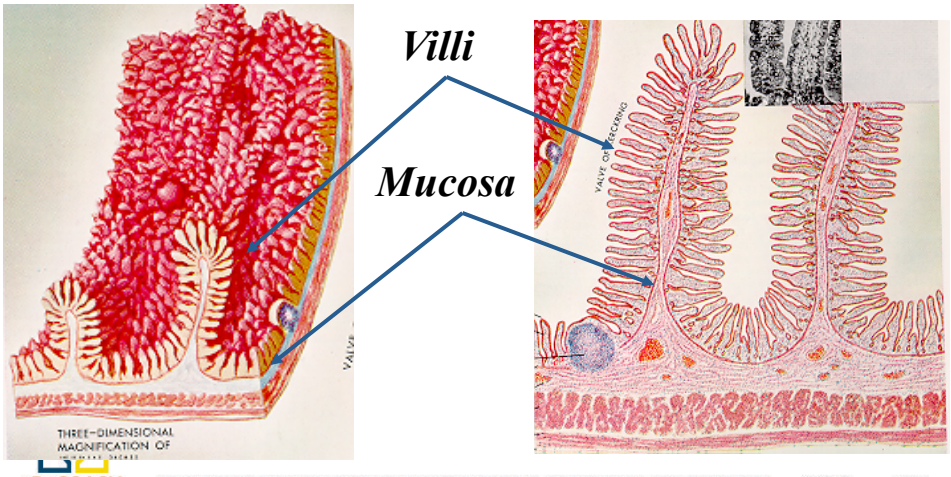


Small Intestine - Structure

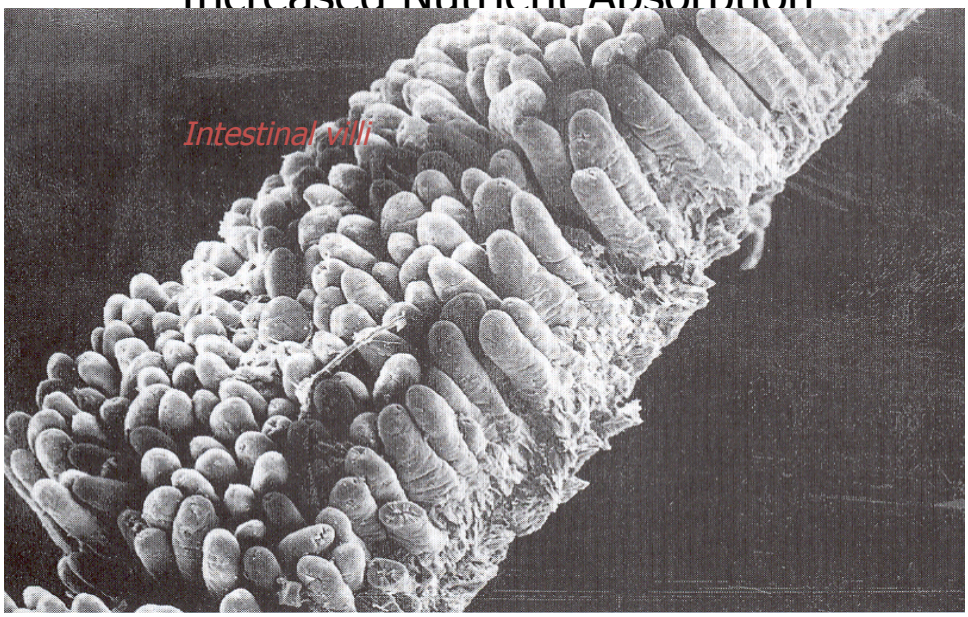
- Lumen
- Mucosa
- Villi
- Crypts
- Lacteal
- Enterocyte
- Brush border



Intestinal Wall



Enhanced Surface Area for Increased Nutrient Absorption



Nutrient Absorption in the Small Intestine

- Principal site of absorption of amino acids, vitamins, minerals and lipids
  - Glucose and other sugars in monogastrics
- Generally, most absorption occurs in the proximal (upper) part of the small intestine but some absorption occurs in all segments
  - Duodenum, jejunum and ileum
- Digestion and absorption within SI is rapid
  - Within 30 minutes of entering SI

Nutrient Absorption

- Variety of mechanisms
  - Diffusion
  - Facilitated diffusion
  - Active transport
  - Pinocytosis or endocytosis
- Dependent upon
  - Solubility of the nutrient (fat vs. water)
  - Concentration or electrical gradient
  - Size of the molecule to be absorbed

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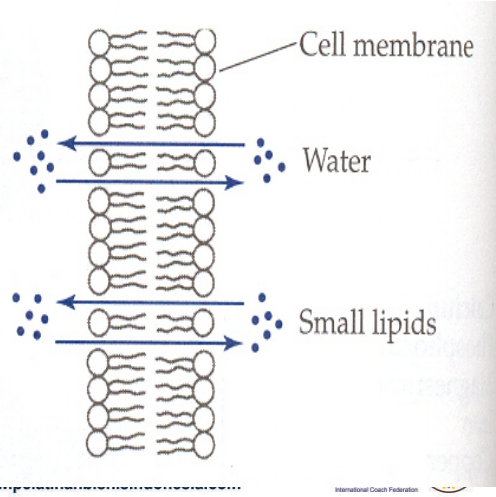
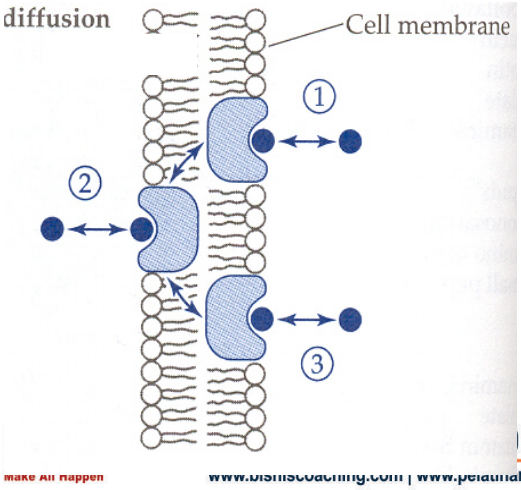
Diffusion

- Water and small lipi molecules pass freely through membrane
- Move down concentration gradient to equalize concentrations



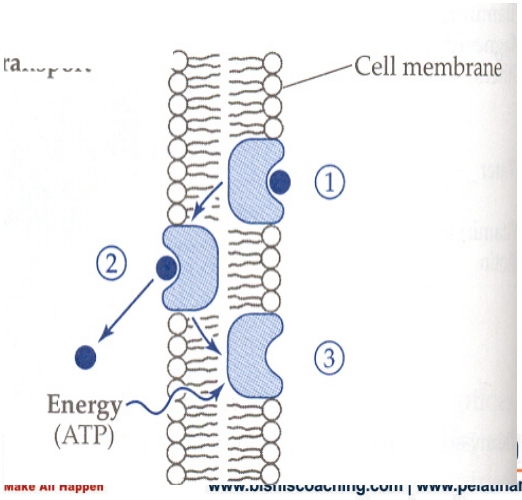
Facilitated Diffusion



1) Carrier loads particle on outside of cell
2) Carrier releases particle on inside of cell
3) Reverse

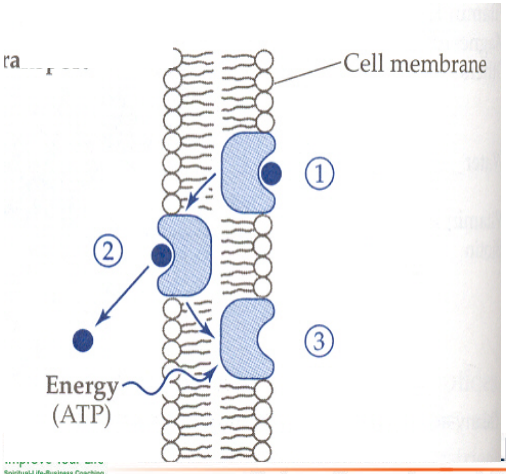
Allows equalization of concentrations across membrane

Active Transport



1) Carrier loads particle on outside of cell
2) Carrier releases particle on inside of cell
3) Carrier returns to outside to pick up another particle

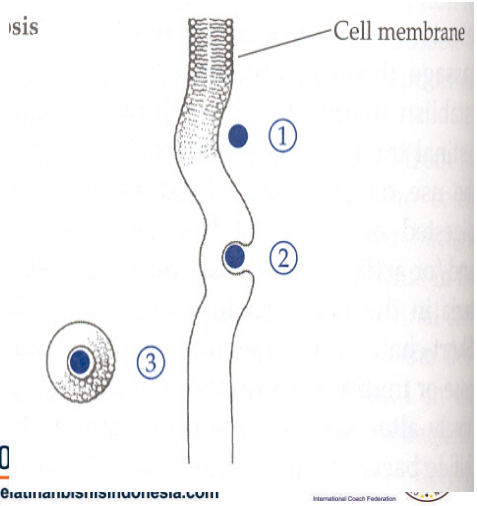
Active Transport



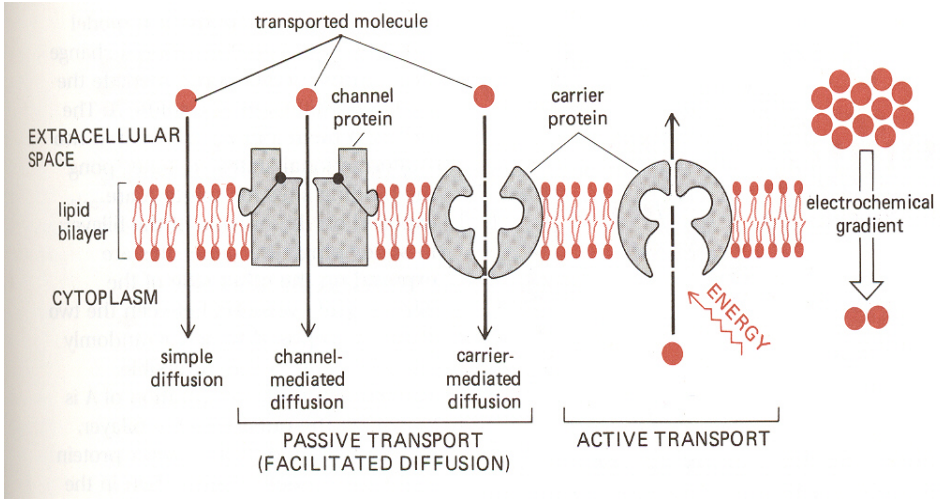
- Unidirectional movement
- Transports nutrients against concentration gradient

Pinocytosis or Endocytosis

- Substance contacts cell membrane
- Membrane wraps around or engulfs substance into sac
- Sac formed separates from the membrane and moves into cell



Transporters



Secretions Entering SI

- Intestinal mucus
- Brush border enzymes
- Pancreatic juices
  - Produced & stored in pancreas

Secreted from within SI

- Bile
  - Produced in liver
  - Stored in gallbladder
  - Horse has no gallbladder
    - Direct bile secretion into duodenum
    - Cannot store bile—continuous intake of food

Enters from ducts into SI

Intestinal Mucus

- Secreted by glands in wall of duodenum
  - Brunner's glands
- Acts as lubricant and buffer to protect duodenal wall

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Primary Enzymes for Carbohydrates

Nutrient	Enzyme	Origin	Product
Starch, glycogen, dextrin	Amylase	Saliva & pancreas	Maltose & Glucose
Maltose	Maltase	SI	Glucose
Lactose	Lactase	SI	Glucose & galactose
Sucrose	Sucrase	SI	Glucose & fructose

Primary Enzymes for Proteins

Nutrient	Enzyme	Origin	Product
Milk protein	Rennin	Gastric mucosa	Curd
Proteins	Pepsin	Gastric mucosa	Polypeptide
Polypeptides	Trypsin Chymotrypsin	Pancreas Pancreas	Peptides Peptides
Peptides	Carboxypeptidase Aminopeptidase	Pancreas Small intestine	Peptides & amino acids

Primary Enzymes for Lipids

Nutrient	Enzyme	Origin	Product
Lipids	Lipase & colipase	Pancreas	Monoglycerides & free fatty acids

Bile

- Green, viscous liquid
  - Alkaline ph (neutralize acidic chyme)
- Secreted by liver via bile duct to duodenum
  - Stored in gall bladder (except in horses)
- Functions to emulsify fats
- Composition
  - Bile salts (glycocholic and taurocholic acids)
  - Bile pigments (bilirubin and biliverdin)
  - Cholesterol
- 95% reabsorbed and returned to liver
- NOT AN ENZYME

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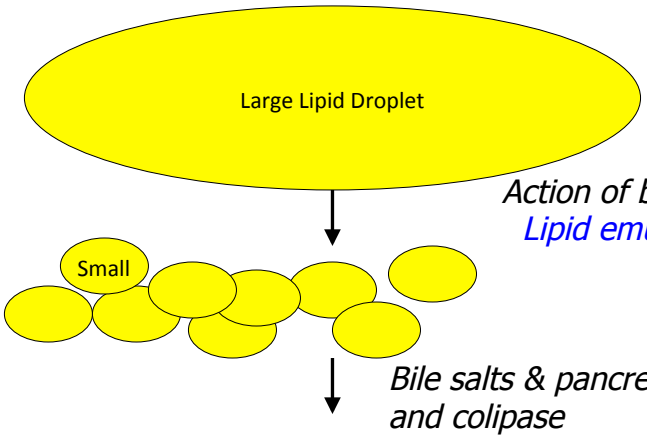
Nutrient Digestion - Lipids



Pancreatic Juice

- Clear, watery juice
- Enters duodenum via pancreatic duct
- Aids in fat, starch, and protein digestion

- Contains
  - HCO_3^-
  - Trypsinogen
  - Chymotrypsinogen
  - Procarboxypeptidase
  - Amylase
  - Lipase
  - Nuclease

Pro-enzymes

Importance of Pancreas for Digestion

- Produces enzymes responsible for
  - 50% of carbohydrate digestion
  - 50% of protein digestion
  - 90% of lipid digestion
- Produces sodium bicarbonate for neutralization of chyme in duodenum

Activation of Pancreatic Enzymes

- Enterokinase
  - Secreted from crypts in duodenum
  - Trypsinogen ⟶ trypsin
- Trypsin then converts:
  - Trypsinogen ⟶ trypsin
  - Chymotrypsinogen ⟶ chymotrypsin
  - Procarboxypeptidase ⟶ carboxypeptidase

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Overview of Digestive Enzymes

- Stomach
  - Pepsinogen
  - Chymosin (rennin)
- Pancreas
  - Trypsinogen
  - Chymotrypsinogen
  - Procarboxypeptidase
  - Amylase
  - Lipase
  - Nuclease
- Brush Border (SI)
  - Sucrase
  - Maltase
  - Lactase
  - Aminopeptidase
  - Dipeptidase
  - Enterokinase

Large Intestine

- Composed of three segments
  - Cecum
  - Colon
  - Rectum
- Function
  - Fermentative digestion
    - No enzyme secretion
    - Relies on microbes or secretions washed out of the SI
  - Absorption of remaining water, volatile fatty acids (VFAs) from microbial fermentation and minerals
  - Digesta storage

Degree of development is species dependent

Monogastric Cecum

- Located at junction of small and large intestine
- Function similar to rumen in ruminants
  - Microbial activity and digestion of feeds
    - Contains a microbial population similar to the rumen
      - Cellulolytic & hemicelluloytic bacteria
- Since cecum is located AFTER major site of nutrient absorption (small intestine), then microbial cell proteins are not available to the animal
  - Fecal loss

Monogastric Large Intestine

- Function:
  - Absorption of liquid
  - Mass movements move fecal matter to anus
  - Usually only a few times a day
    - Associated with defecation

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Bacteria

- Cellulolytic – digest cellulose (forages)
- Amylolytic – digest starches and sugars (concentrates or grains)
- Other types:
  - Proteolytic
    - Clostridium
  - Organic acid utilizers
  - Methanogens
    - Produce CO_2, H_2, formate, CH_4

Rectum

- Muscular area of large intestine used for storage of feces and ultimately for defecation
  - Feces includes sloughed cells, undigested food and microbial matter

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Avians (Poultry)

Mouth

- No teeth, rigid tongue
- Poorly developed salivary glands
  - Saliva contains amylase
- Beak is adapted for prehension and mastication

Avians (Poultry)

Esophagus

- Enlarged area called crop
  - Ingesta holding and moistening
  - Location for breakdown of carbohydrate by amylase
  - Fermentation

Proventriculus (stomach)

- Release of HCl and pepsin (gastric juices)
- Ingesta passes through very quickly (14 seconds)

Avians (Poultry)

Gizzard (ventriculus)

- Muscular area with a hardened lining reduces particle size
  - Muscular contractions every 20-30 seconds
  - Includes action of grit
  - HCl and pepsin secreted in proventriculus

Small intestine

- Similar to other monogastrics
- No Lacteals

Avians (Poultry)

Ceca and large intestine

- Contain two ceca instead of one as in other monogastrics
- Large intestine is very short (2-4 in) and empties into cloaca where fecal material will be voided via the vent
  - Water resorption
  - Fiber fermentation by bacteria
  - H_2O soluble vitamin synthesis by bacteria