ANIMAL NUTRITION

Food Types and Feeding Mechanisms

- **Most animals are opportunistic feeders**
- Animals fit into one of three dietary categories.
  - **Herbivores**, such as gorillas, cows, hares, and many snails, eat mainly autotrophs (plants, algae).
  - **Carnivores** , such as sharks, hawks, spiders, and snakes, eat other animals.
  - **Omnivores**, such as cockroaches, bears, raccoons, and humans, consume animal and plant or algal matter.

Mechanisms by which animals ingest food

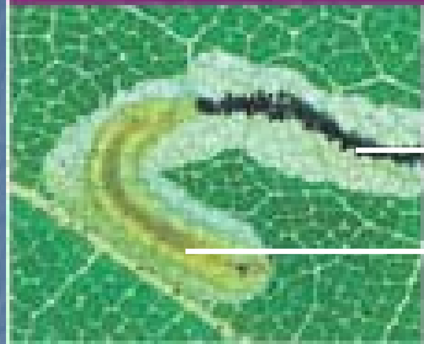
Four main groups

- **Suspension-feeders** that sift small food particles from the water.
- **Substrate-feeders** live in or on their food source, eating their way through the food.
  - **Deposit-feeders**, like earthworms, eat their way through dirt or sediments and extract partially decayed organic material consumed along with the soil or sediments.
- **Fluid-feeders** make their living sucking nutrient-rich fluids from a living host and are considered parasites.
- **Bulk-feeders:** Most animals, that eat relatively large pieces of food.

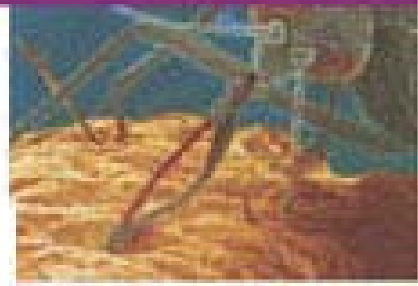
Four Main Feeding Mechanisms of Animals

SUSPENSION FEEDERS

SUBSTRATE FEEDERS



FLUID FEEDERS



BULK FEEDERS

Nutritional Requirements

- Animals are heterotrophs that require food for three needs
  - **fuel (chemical energy)** for all the cellular work of the body;
  - the organic **raw materials** animals use in **biosynthesis** (carbon skeletons to make many of their own molecules);
  - **essential nutrients**, substances that the animals cannot make for itself from *any* raw material and therefore must obtain in food in prefabricated form.

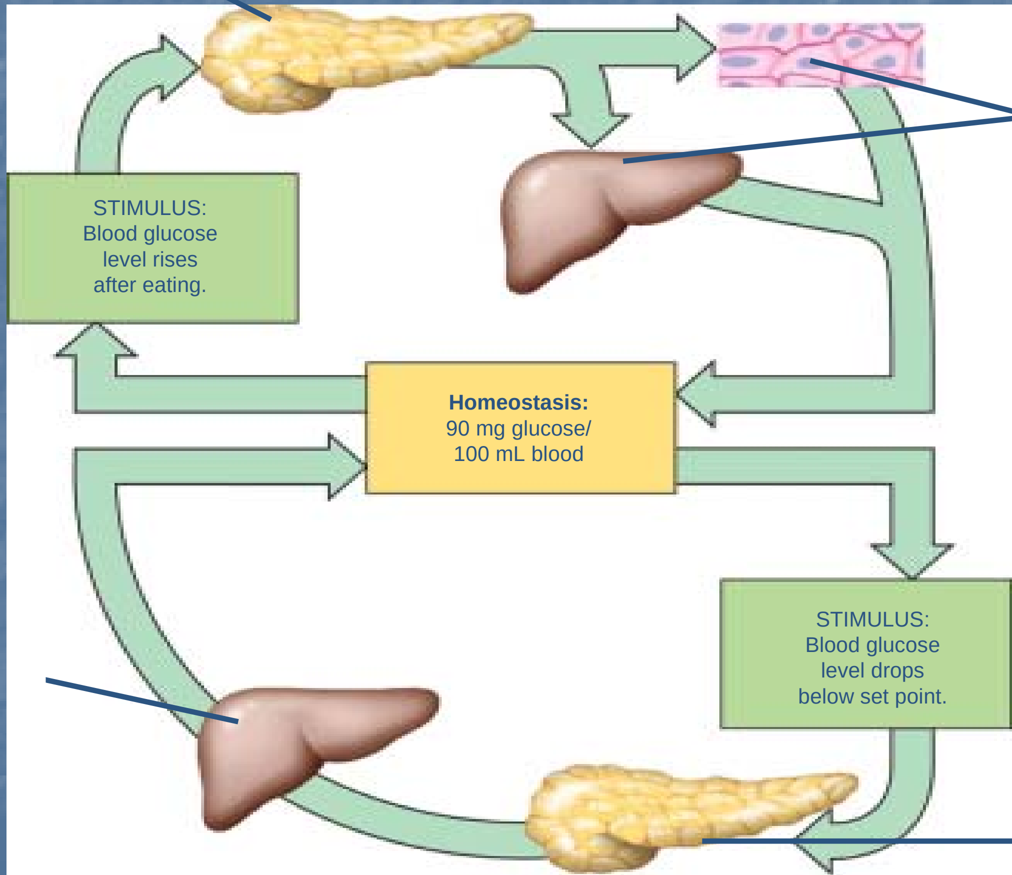
Homeostatic mechanisms manage an animal's fuel

- ATP powers basal or resting metabolism, activity,….
- All ATP is derived from oxidation of organic fuel molecules - carbohydrates, proteins, and fats - in cellular respiration
- The excess ATP can be used for biosynthesis.
  - used to grow in size or for reproduction, or can be stored in energy depots.
  - In humans, the liver and muscle cells store energy as glycogen.
  - If glycogen stores are full, the excess is usually stored as fat.

Glucose, a major cellular fuel

1 When blood glucose level rises, a gland called the pancreas secretes insulin, a hormone, into the blood.

2 Insulin enhances the transport of glucose into body cells and stimulates the liver and muscle cells to store glucose as glycogen. As a result, blood glucose level drops.



3 When blood glucose level drops, the pancreas secretes the hormone glucagon, which opposes the effect of insulin.

4 Glucagon promotes the breakdown of glycogen in the liver and the release of glucose into the blood, increasing blood glucose level.

Caloric Imbalance

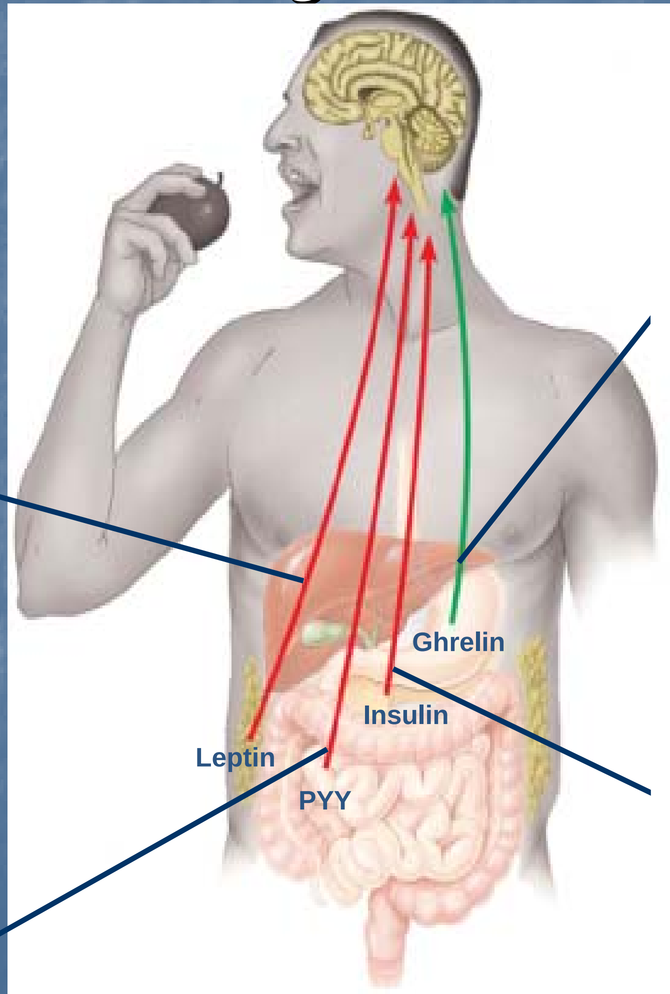
- **Undernourishment:** If the diet of a person or other animal is chronically deficient in calories.
  - even if a seriously undernourished person survives, some damage may be irreversible.
- **Overnourishment**, or obesity, the result from excessive food intake
  - The human body tends to store any excess fat molecules obtained from food instead of using them for fuel.

Obesity as a Human Health Problem

- The World Health Organization
  - Now recognizes obesity as a major global health problem
- Obesity contributes to a number of health problems, including
  - Diabetes, cardiovascular disease, and colon and breast cancer

Appetite regulation

- Regulate both long-term and short-term appetite by affecting a "**satiety center**" in the brain



Secreted by the stomach wall, **ghrelin** is one of the signals that triggers feelings of hunger as mealtimes approach. In dieters who lose weight, ghrelin levels increase, which may be one reason it's so hard to stay on a diet.

Produced by adipose (fat) tissue, **leptin** suppresses appetite as its level increases. When body fat decreases, leptin levels fall, and appetite increases.

The hormone **PYY,** secreted by the small intestine after meals, acts as an appetite suppressant that counters the appetite stimulant ghrelin.

A rise in blood sugar level after a meal stimulates the pancreas to secrete **insulin**. In addition to its other functions, insulin suppresses appetite by acting on the brain.

Leptin

- Leptin, produced by adipose cells, is a key player in a complex feedback mechanism regulating fat storage and use.
  - A high leptin level:
    - the brain to depress appetite
    - to increase energy-consuming muscular activity and body-heat production.
  - Decreasing leptin levels: signaling the brain to increase appetite and weight gain.


Benjamin
Cummings

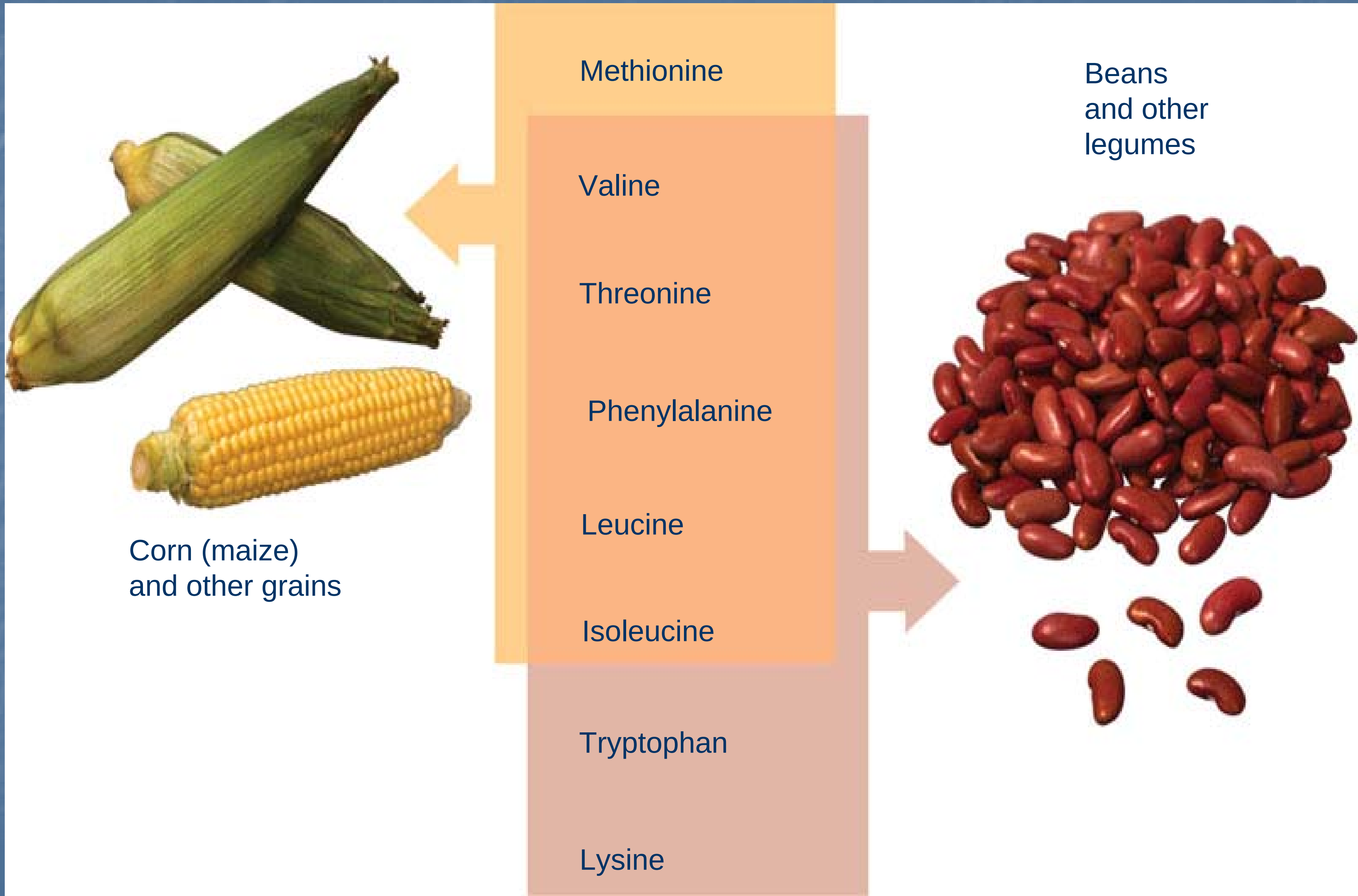
An animal's diet must supply essential nutrients and carbon skeletons for biosynthesis

- **Essential nutrients**
  - These are materials that must be obtained in preassembled form because the animal's cells cannot make them from *any* raw material.
- **Malnourishment:** An animal whose diet is missing one or more essential nutrients .

Essential amino acids

- Animals require 20 amino acids to make proteins.
  - Most animals can synthesize half of these if their diet includes organic nitrogen
  - Eight amino acids are essential in the adult human with a ninth, histidine, essential for infants.
- The proteins in animals products, such as meat, eggs, and cheese, are "complete."
- Most plant proteins are "incomplete."

Essential amino acids for adults



Essential fatty acids.

- These are certain unsaturated fatty acids, including linoleic acids required by humans.

Vitamins

- Organic molecules required in the diet in quantities that are quite small.
- 13 vitamins essential to humans have been identified.
  - These can be grouped into water-soluble vitamins and fat-soluble vitamins, with extremely diverse physiological functions.

Table 41.1 Vitamin Requirements of Humans

Vitamin	Major Dietary Sources	Some Major Functions in the Body	Possible Symptoms of Deficiency or Extreme Excess
Water-Soluble Vitamins			
Vitamin B_1 (thiamine)	Pork, legumes, peanuts, whole grains	Coenzyme used in removing CO_2 from organic compounds	Beriberi (nerve disorders, emaciation, anemia)
Vitamin B_2 (riboflavin)	Dairy products, meats, enriched grains, vegetables	Component of coenzymes FAD and FMN	Skin lesions such as cracks at corners of mouth
Niacin	Nuts, meats, grains	Component of coenzymes NAD^+ and $NADP^+$	Skin and gastrointestinal lesions, nervous disorders **Liver damage**
Vitamin B_6 (pyridoxine)	Meats, vegetables, whole grains	Coenzyme used in amino acid metabolism	Irritability, convulsions, muscular twitching, anemia **Unstable gait, numb feet, poor coordination**
Pantothenic acid	Most foods: meats, dairy products, whole grains, etc.	Component of coenzyme A	Fatigue, numbness, tingling of hands and feet
Folic acid (folacin)	Green vegetables, oranges, nuts, legumes, whole grains	Coenzyme in nucleic acid and amino acid metabolism	Anemia, gastrointestinal problems **May mask deficiency of vitamin B_{12}**
Vitamin B_{12}	Meats, eggs, dairy products	Coenzyme in nucleic acid metabolism; maturation of red blood cells	Anemia, nervous system disorders
Biotin	Legumes, other vegetables, meats	Coenzyme in synthesis of fat, glycogen, and amino acids	Scaly skin inflammation, neuromuscular disorders
Vitamin C (ascorbic acid)	Fruits and vegetables, especially citrus fruits, broccoli, cabbage, tomatoes, green peppers	Used in collagen synthesis (such as for bone, cartilage, gums); antioxidant; aids in detoxification; improves iron absorption	Scurvy (degeneration of skin, teeth, blood vessels), weakness, delayed wound healing, impaired immunity **Gastrointestinal upset**
Fat-Soluble Vitamins			
Vitamin A (retinol)	Provitamin A (beta-carotene) in deep green and orange vegetables and fruits; retinol in dairy products	Component of visual pigments; maintenance of epithelial tissues; antioxidant; helps prevent damage to cell membranes	Vision problems; dry, scaling skin **Headache, irritability, vomiting, hair loss, blurred vision, liver and bone damage**
Vitamin D	Dairy products, egg yolk (also made in human skin in presence of sunlight)	Aids in absorption and use of calcium and phosphorus; promotes bone growth	Rickets (bone deformities) in children, bone softening in adults **Brain, cardiovascular, and kidney damage**
Vitamin E (tocopherol)	Vegetable oils, nuts, seeds	Antioxidant; helps prevent damage to cell membranes	None well documented in humans; possibly anemia
Vitamin K (phylloquinone)	Green vegetables, tea (also made by colon bacteria)	Important in blood clotting	Defective blood clotting **Liver damage and anemia**

Minerals

- are simple inorganic nutrients
- Mineral requirements vary with animal species.

Table 41.2 Mineral Requirements of Humans

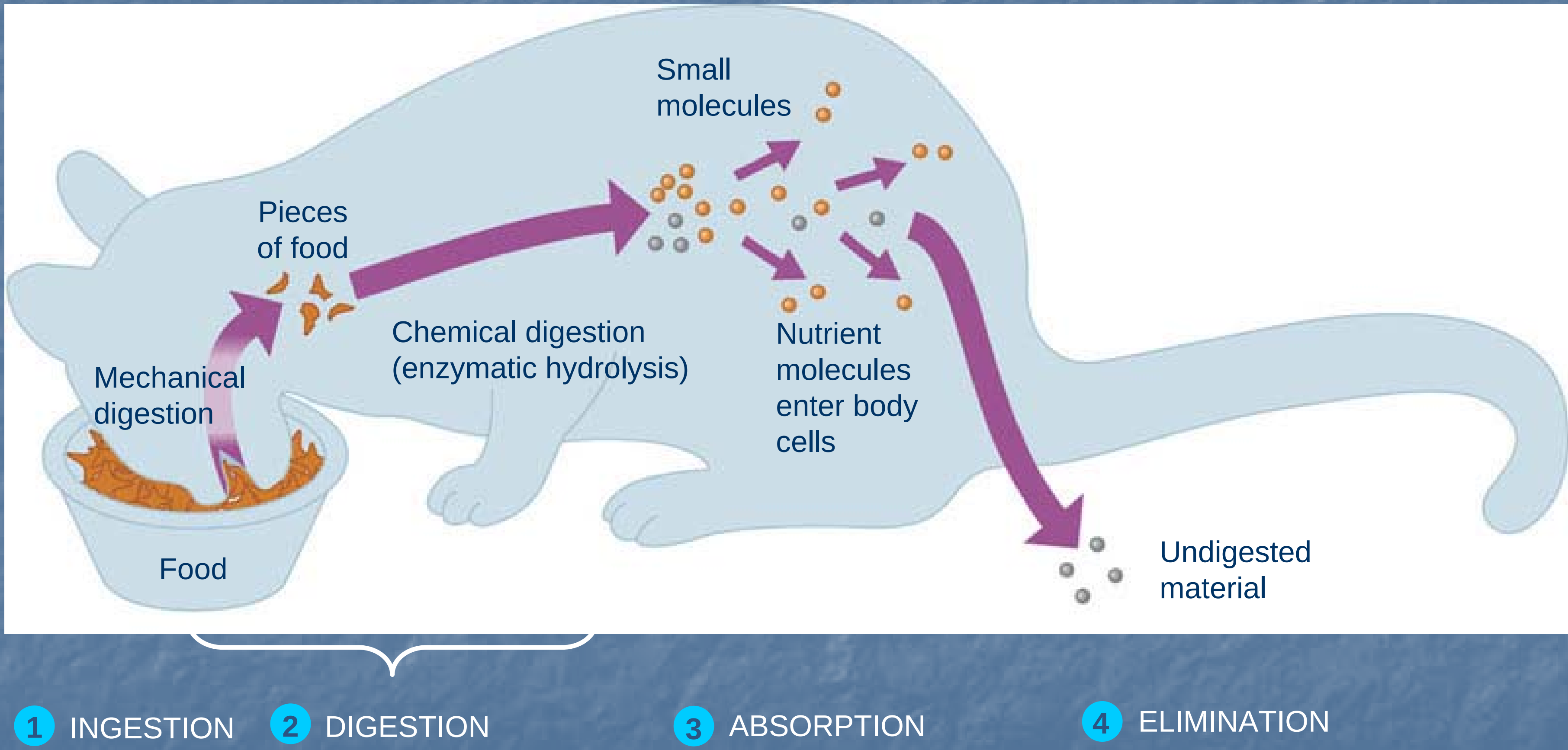
Mineral	Major Dietary Sources	Some Major Functions in the Body	Possible Symptoms of Deficiency*
Calcium (Ca)	Dairy products, dark green vegetables, legumes	Bone and tooth formation, blood clotting, nerve and muscle function	Retarded growth, possibly loss of bone mass
Phosphorus (P)	Dairy products, meats, grains	Bone and tooth formation, acid-base balance, nucleotide synthesis	Weakness, loss of minerals from bone, calcium loss
Sulfur (S)	Proteins from many sources	Component of certain amino acids	Symptoms of protein deficiency
Potassium (K)	Meats, dairy products, many fruits and vegetables, grains	Acid-base balance, water balance, nerve function	Muscular weakness, paralysis, nausea, heart failure
Chlorine (Cl)	Table salt	Acid-base balance, formation of gastric juice, nerve function, osmotic balance	Muscle cramps, reduced appetite
Sodium (Na)	Table salt	Acid-base balance, water balance, nerve function	Muscle cramps, reduced appetite
Magnesium (Mg)	Whole grains, green leafy vegetables	Cofactor; ATP bioenergetics	Nervous system disturbances
Iron (Fe)	Meats, eggs, legumes, whole grains, green leafy vegetables	Component of hemoglobin and of electron carriers in energy metabolism; enzyme cofactor	Iron-deficiency anemia, weakness, impaired immunity
Fluorine (F)	Drinking water, tea, seafood	Maintenance of tooth (and probably bone) structure	Higher frequency of tooth decay
Zinc (Zn)	Meats, seafood, grains	Component of certain digestive enzymes and other proteins	Growth failure, scaly skin inflammation, reproductive failure, impaired immunity
Copper (Cu)	Seafood, nuts, legumes, organ meats	Enzyme cofactor in iron metabolism, melanin synthesis, electron transport	Anemia, bone and cardiovascular changes
Manganese (Mn)	Nuts, grains, vegetables, fruits, tea	Enzyme cofactor	Abnormal bone and cartilage
Iodine (I)	Seafood, dairy products, iodized salt	Component of thyroid hormones	Goiter (enlarged thyroid)
Cobalt (Co)	Meats and dairy products	Component of vitamin B_{12}	None, except as B_{12} deficiency
Selenium (Se)	Seafood, meats, whole grains	Enzyme cofactor; antioxidant functioning in close association with vitamin E	Muscle pain, possibly heart muscle deterioration
Chromium (Cr)	Brewer's yeast, liver, seafood, meats, some vegetables	Involved in glucose and energy metabolism	Impaired glucose metabolism
Molybdenum (Mo)	Legumes, grains, some vegetables	Enzyme cofactor	Disorder in excretion of nitrogen-containing compounds

*All of these minerals are also harmful when consumed in excess.

Food Processing

Four main stages

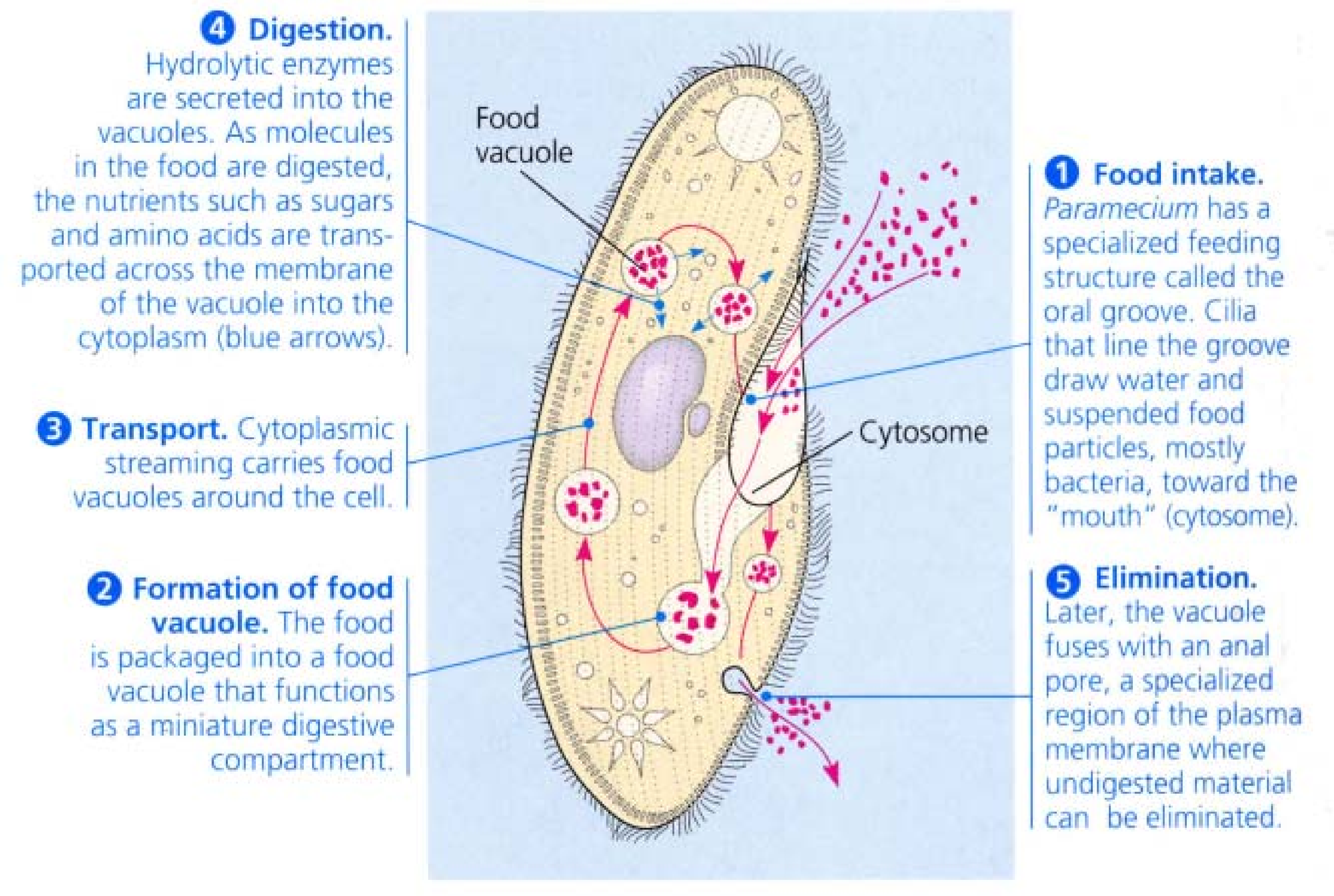
- **Ingestion**, the act of eating
- **Digestion**, is the process of breaking food down into molecules small enough for the body to absorb.
  - digestion breaks bonds with the addition of water via **enzymatic hydrolysis.**
- **Absorption,** the animal's cells take up small molecules such as amino acids and simple sugars from the digestive compartment.
- **Elimination**, undigested material passes out of the digestive compartment.


Small
molecules
Pieces
of food
Chemical digestion
(enzymatic hydrolysis)
Nutrient
molecules
enter body
cells
Mechanical
digestion
Food
Undigested
material
1 INGESTION
2 DIGESTION
3 ABSORPTION
4 ELIMINATION

Digestion occurs in specialized compartments

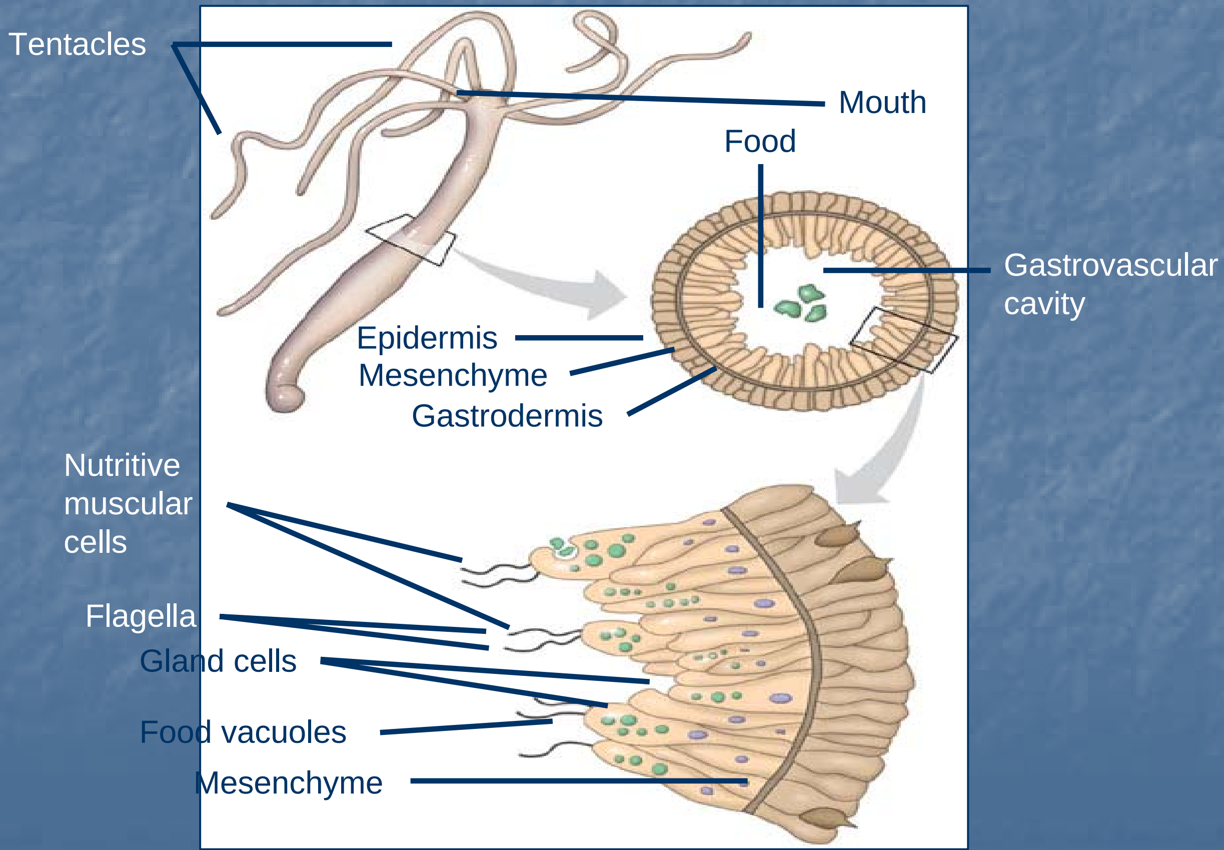
- most organisms conduct digestion in specialized compartments.
- **Intracellular digestion**
- **Extracellular digestion**

Intracellular digestion

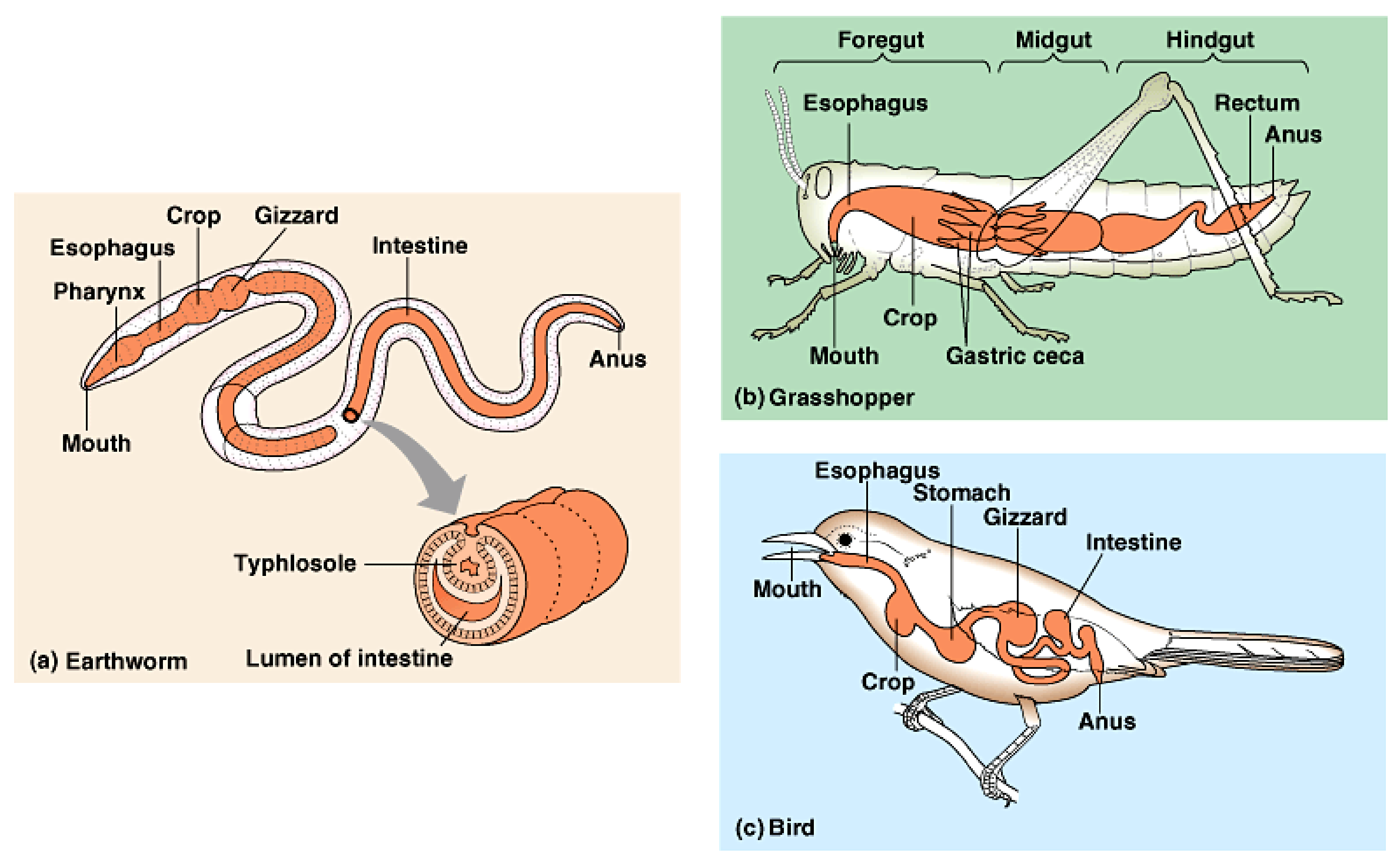


Extracellular digestion

- **Gastrovascular cavities**: animals with simple body plans, such as cnidarians and flatworms, have digestive sacs with single openings.

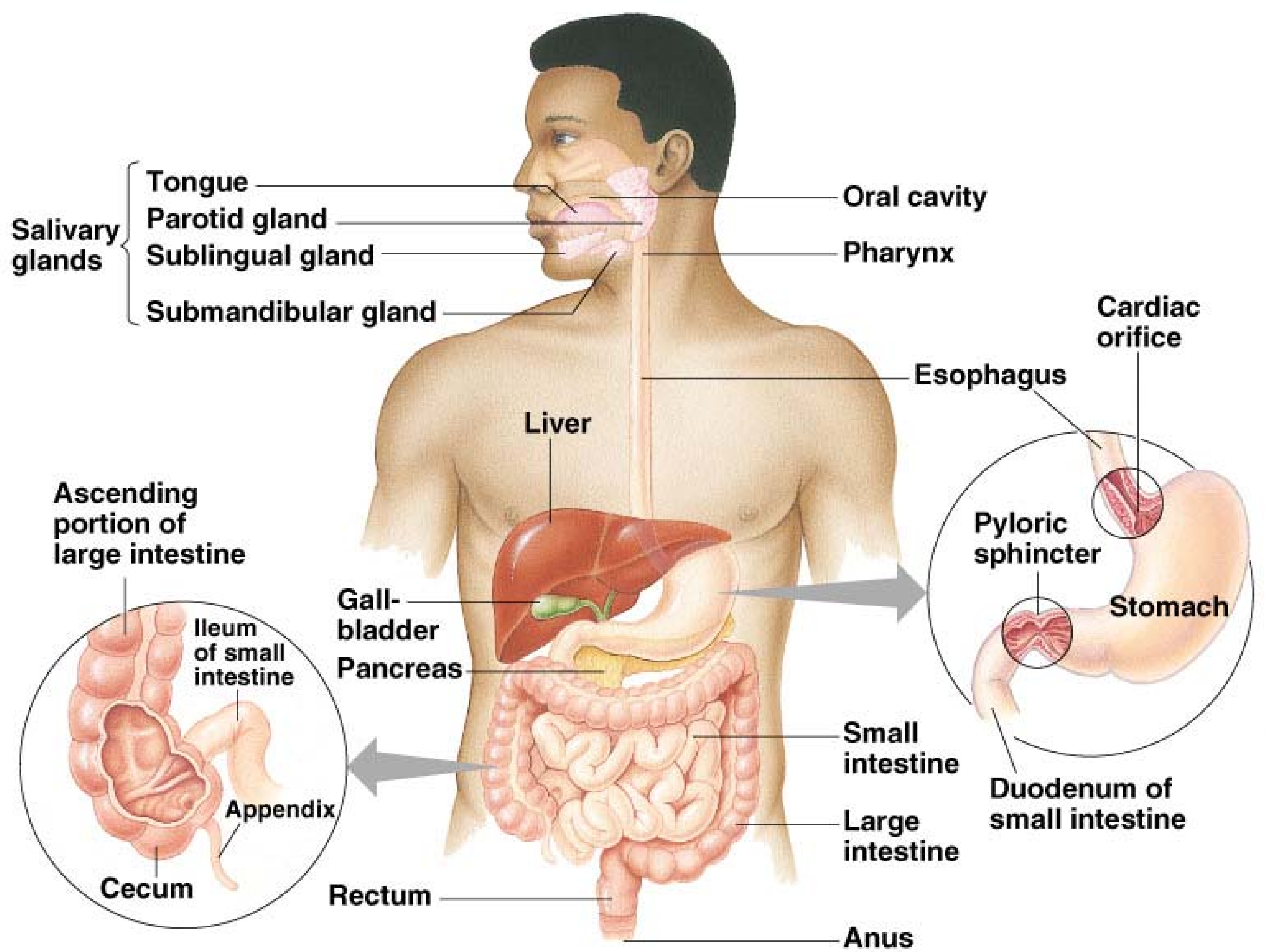


- Most animals have **complete digestive tracts** or **alimentary canals** with a mouth, digestive tube, and an anus.



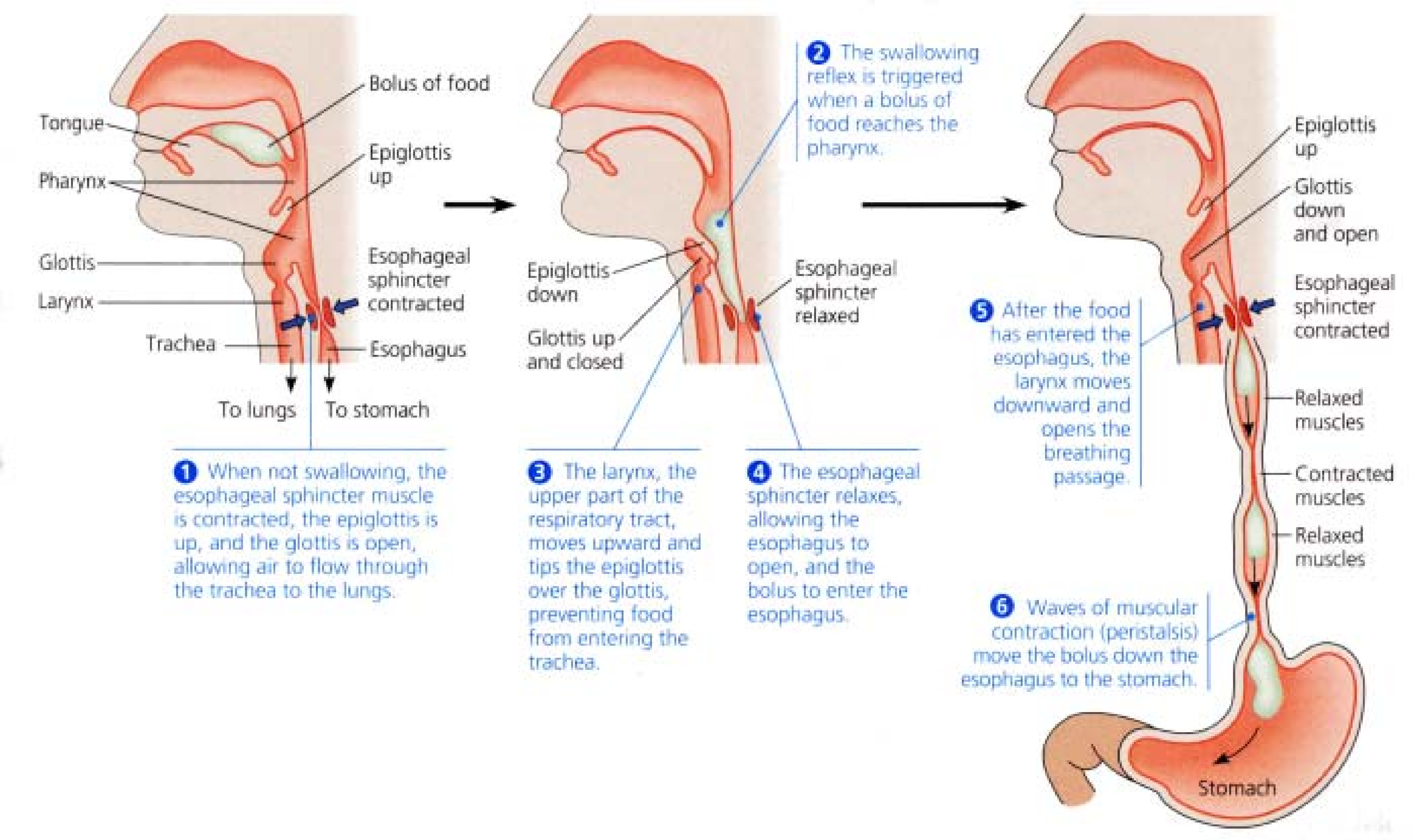
The Mammalian Digestive System

- The mammalian digestive system consists of the alimentary canal and various accessory glands that secrete digestive juices into the canal through ducts.
  - **Peristalsis**, rhythmic waves of contraction by smooth muscles in the walls of the canal, push food along.
  - **Sphincters**, muscular ringlike valves, regulate the passage of material between specialized chambers of the canal.
  - The accessory glands include the **salivary glands**, the **pancreas**, the **liver**, and the **gallbladder**.


Salivary glands
Tongue
Parotid gland
Sublingual gland
Submandibular gland
Oral cavity
Pharynx
Cardiac orifice
Esophagus
Liver
Ascending portion of large intestine
Pyloric sphincter
Gall-bladder
Stomach
Ileum of small intestine
Pancreas
Small intestine
Appendix
Duodenum of small intestine
Large intestine
Cecum
Rectum
Anus

The oral cavity, pharynx, and esophagus initiate food processing

- Chemical digestion of carbohydrates, a main source of chemical energy, begins in the oral cavity.
  - Saliva contains **salivary amylase**
  - The tongue tastes food, and helps shape the food into a ball called a **bolus**.

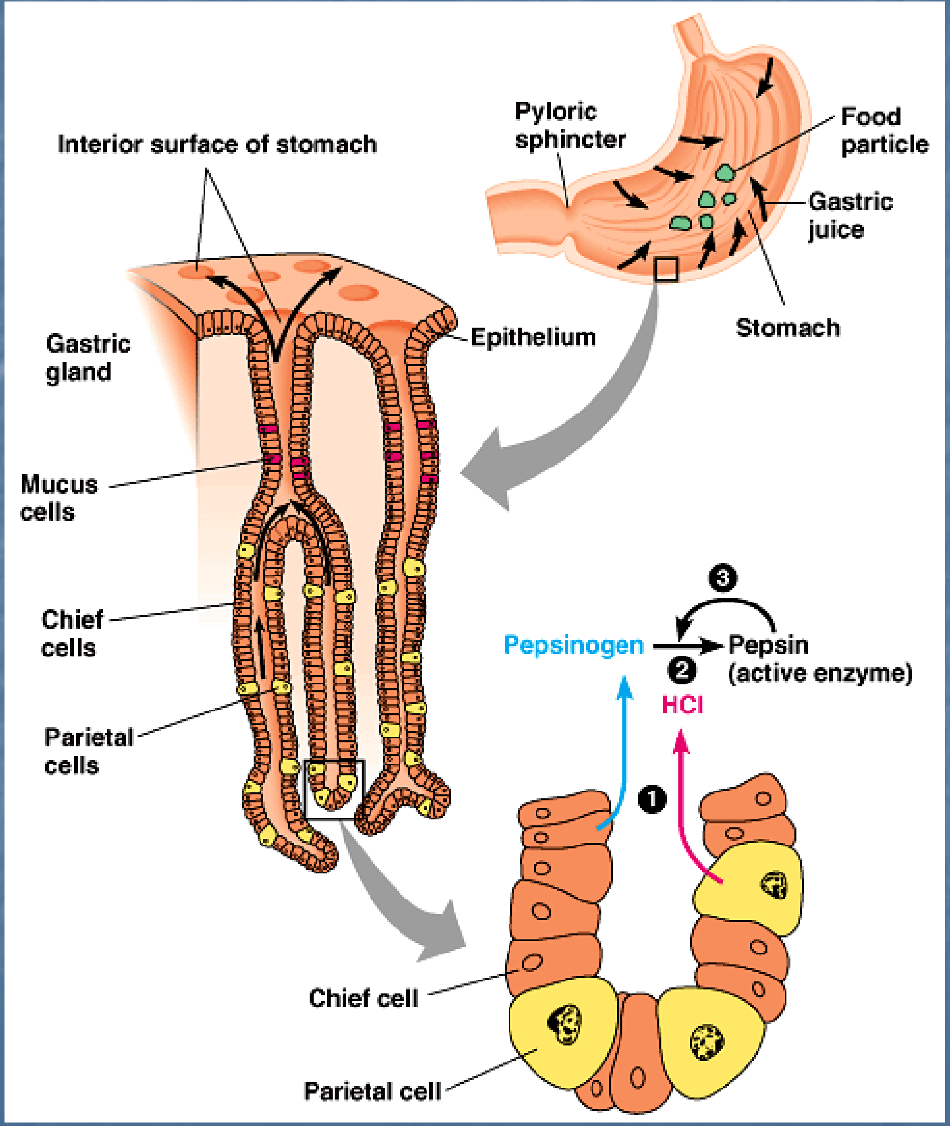

Tongue
Pharynx
Glottis
Larynx
Trachea
Bolus of food
Epiglottis up
Esophageal sphincter contracted
Esophagus
To lungs
To stomach
1 When not swallowing, the esophageal sphincter muscle is contracted, the epiglottis is up, and the glottis is open, allowing air to flow through the trachea to the lungs.
2 The swallowing reflex is triggered when a bolus of food reaches the pharynx.
Epiglottis down
Glottis up and closed
Esophageal sphincter relaxed
3 The larynx, the upper part of the respiratory tract, moves upward and tips the epiglottis over the glottis, preventing food from entering the trachea.
4 The esophageal sphincter relaxes, allowing the esophagus to open, and the bolus to enter the esophagus.
Epiglottis up
Glottis down and open
Esophageal sphincter contracted
5 After the food has entered the esophagus, the larynx moves downward and opens the breathing passage.
Relaxed muscles
Contracted muscles
Relaxed muscles
6 Waves of muscular contraction (peristalsis) move the bolus down the esophagus to the stomach.
Stomach

The stomach stores food and performs preliminary digestion

- The stomach also secretes a digestive fluid called **gastric juice** and mixes this secretion with the food
  - Gastric juice is secreted by the epithelium lining.
  - With a high concentration of **hydrochloric acid**, the pH of the gastric juice is about 2.
  - Also present in gastric juice is **pepsin**, an enzyme that begins the hydrolysis of proteins.

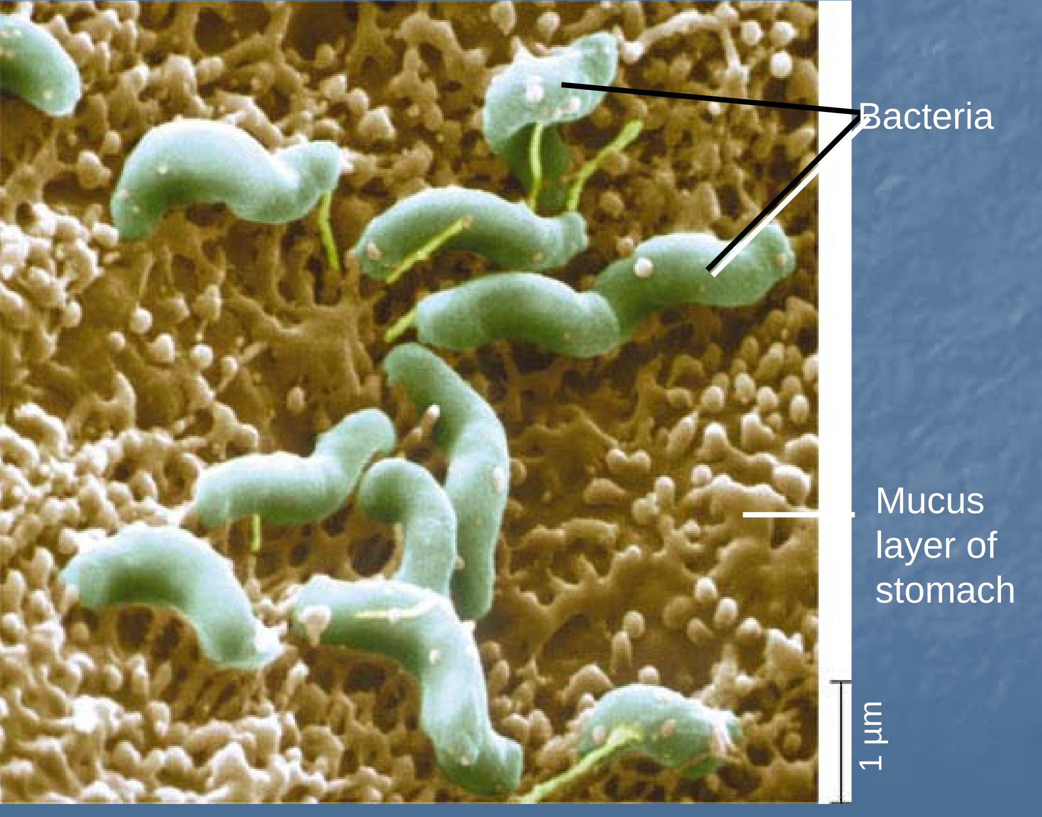
Mechanism against self-digestion

- Pepsin is secreted in an *inactive* form, called **pepsinogen** by specialized chief cells in gastric pits.
  - Parietal cells, also in the pits, secrete hydrochloric acid which converts pepsinogen to the active pepsin.



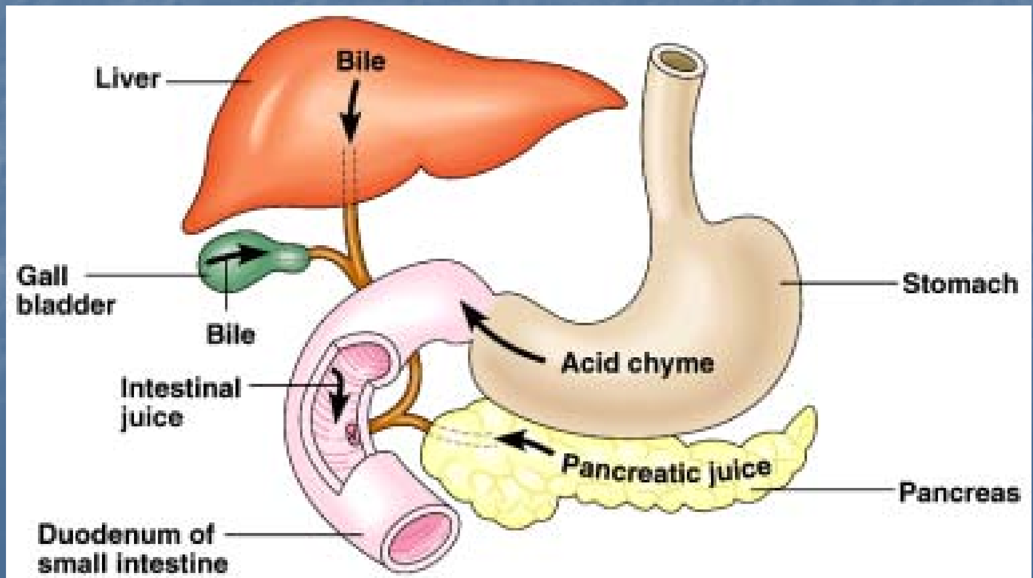
- A coating of mucus, secreted by epithelial cells, that protects the stomach lining
- Epithelium is completely replaced by mitosis every three days.
- Gastric ulcers, lesions in the stomach lining, are caused by the acid-tolerant bacterium *Heliobacter pylori*.
  - Ulcers are often treated with antibiotics
- About every 20 seconds, the stomach contents are mixed: **acid chyme.**

Helicobacter pylori

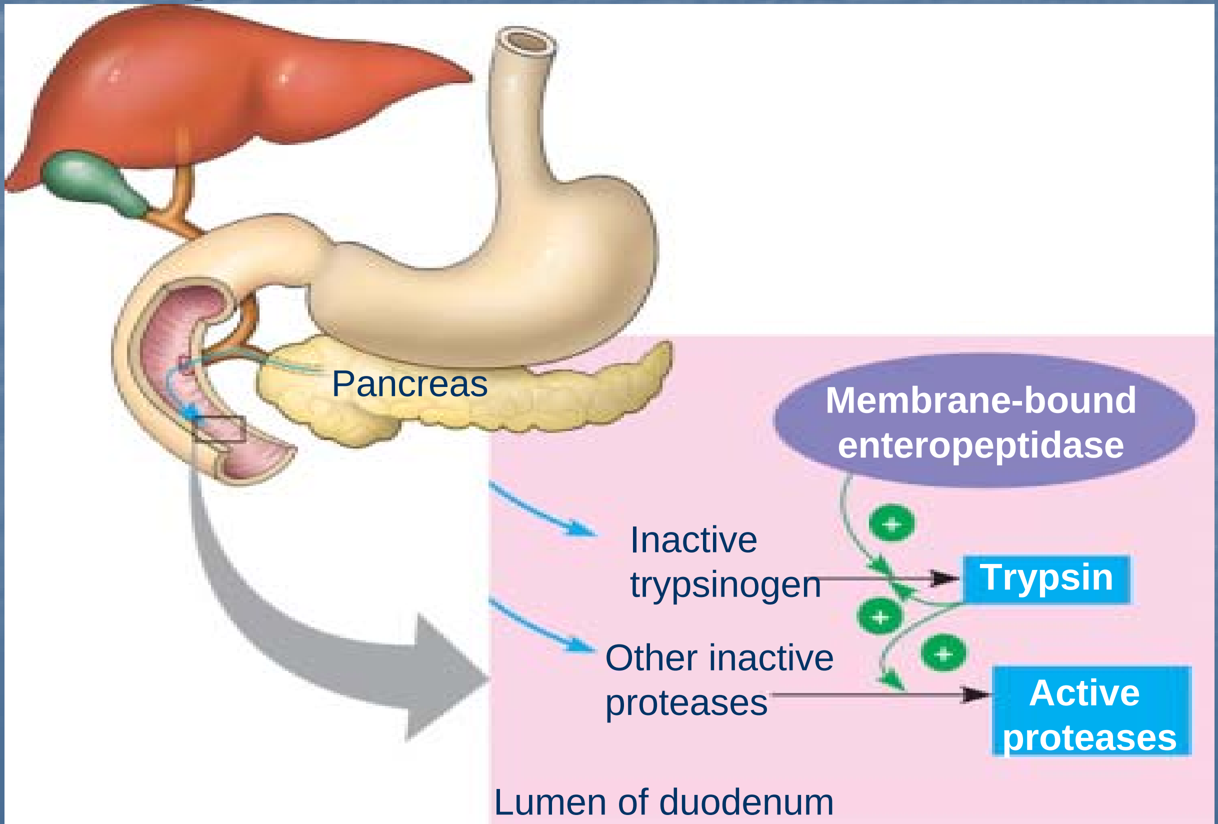


The small intestine

- **the major organ of digestion and absorption.**
  - With a length of over 6 m in humans
  - In the first 25 cm or so of the small intestine, the **duodenum**



- Many of the protein-digesting enzymes are secreted by the intestinal epithelium, but trypsin, chymotrypsin, and Carboxypeptidase are secreted in inactive form by the pancreas.

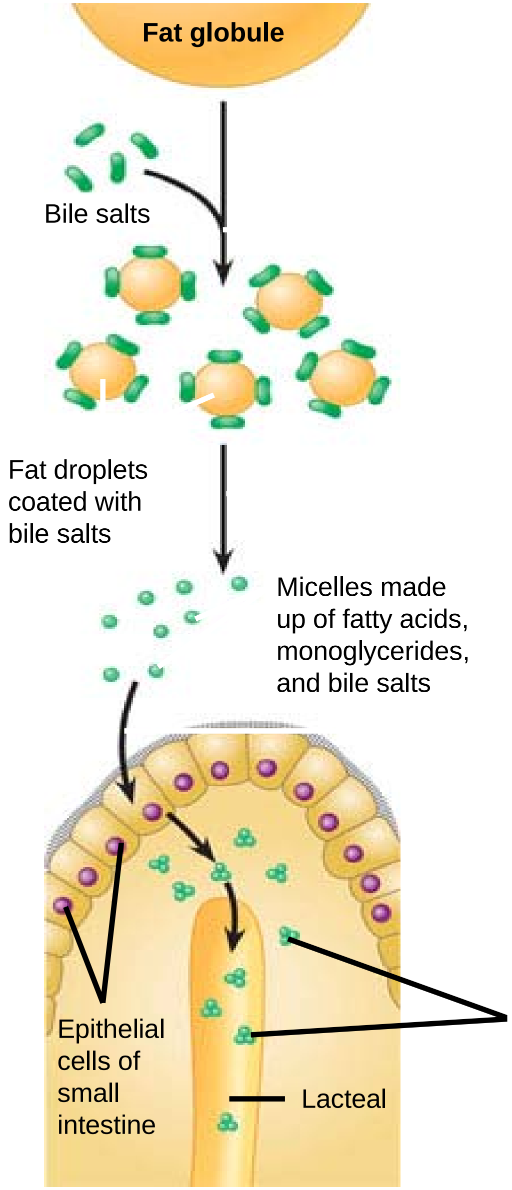


	Carbohydrate digestion	Protein digestion	Nucleic acid digestion	Fat digestion
Oral cavity, pharynx, esophagus	Polysaccharides (starch, glycogen) → Salivary amylase → Smaller polysaccharides, maltose; Disaccharides (sucrose, lactose)			
Stomach		Proteins → Pepsin → Small polypeptides		
Lumen of small intestine	Polysaccharides → Pancreatic amylases → Maltose and other disaccharides	Polypeptides → Pancreatic trypsin and chymotrypsin (These proteases cleave bonds adjacent to certain amino acids.) → Smaller polypeptides → Pancreatic carboxypeptidase → Amino acids	DNA, RNA → Pancreatic nucleases → Nucleotides	Fat globules (Insoluble in water, fats aggregate as globules.) → Bile salts → Fat droplets (A coating of bile salts prevents small droplets from coalescing into larger globules, increasing exposure to lipase.) → Pancreatic lipase → Glycerol, fatty acids, glycerides
Epithelium of small intestine (brush border)	Disaccharidases → Monosaccharides	Small peptides → Dipeptidases, carboxypeptidase, and aminopeptidase (These proteases split off one amino acid at a time, working from opposite ends of a polypeptide.) → Amino acids	Nucleotidases → Nucleosides → Nucleosidases and phosphatases → Nitrogenous bases, sugars, phosphates	

Fat digestion

- Normally fat molecules are insoluble in water, but bile salts, secreted by the gallbladder into the duodenum, coat tiny fats droplets and keep them from coalescing, a process known as **emulsification**.
- The large surface area of these small droplets is exposed to **lipase**, an enzyme that hydrolyzes fat molecules into glycerol, fatty acids, and glycerides.
- The fats are mixed with cholesterol and coated with special proteins to form small globules called **chylomicrons**.

Digestion and absorption of fats



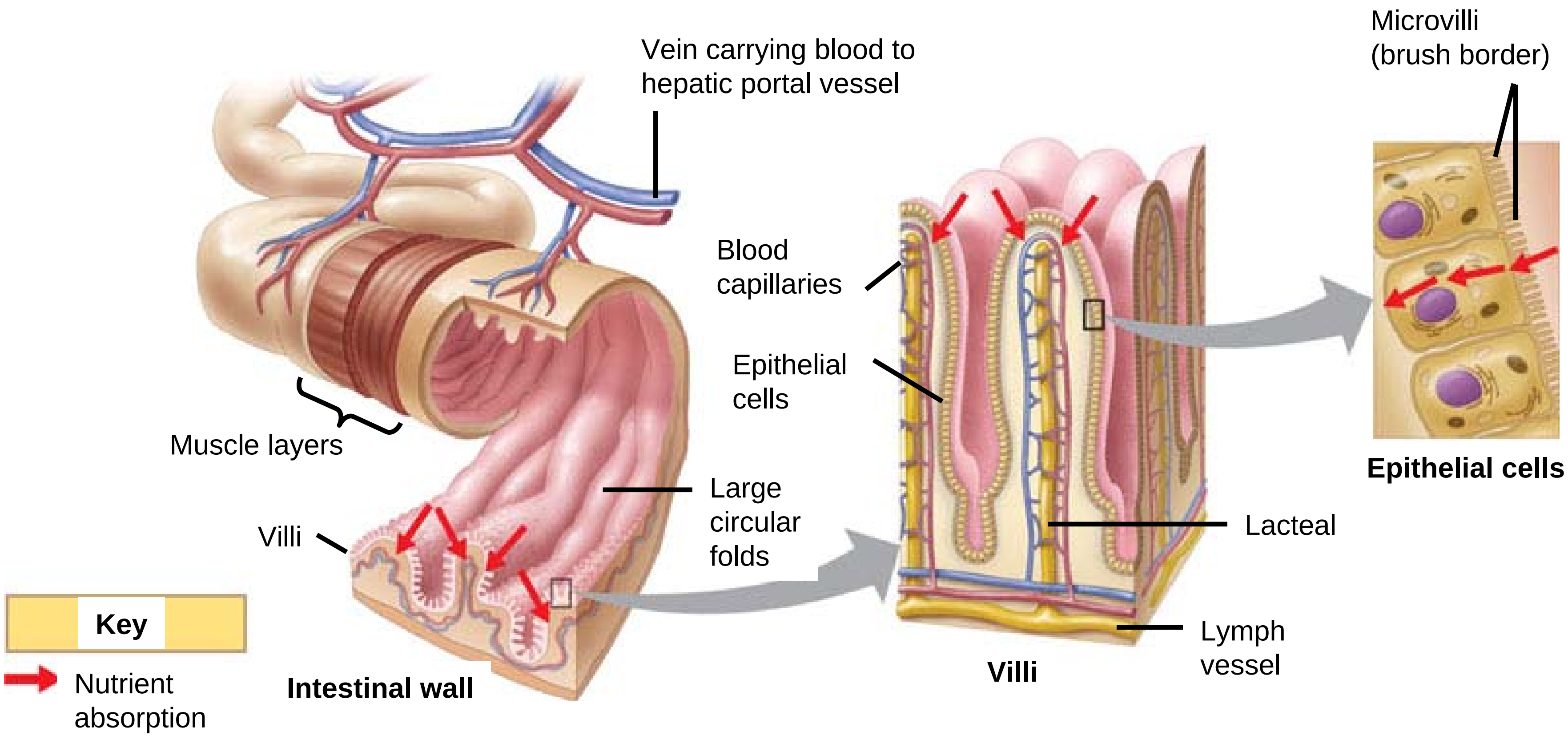
1 Large fat globules are emulsified by bile salts in the duodenum.

2 Digestion of fat by the pancreatic enzyme lipase yields free fatty acids and monoglycerides, which then form micelles.

3 Fatty acids and monoglycerides leave micelles and enter epithelial cells by diffusion.

4 Chylomicrons containing fatty substances are transported out of the epithelial cells and into lacteals, where they are carried away from the intestine by lymph.

- Most digestion occurs in the duodenum.
- The other two sections of the small intestine, the **jejunum** and **ileum**, function mainly in the absorption of nutrients and water.


Vein carrying blood to hepatic portal vessel
Microvilli (brush border)
Blood capillaries
Epithelial cells
Muscle layers
Large circular folds
Villi
Lacteal
Lymph vessel
Key
Nutrient absorption
Intestinal wall
Villi
Epithelial cells

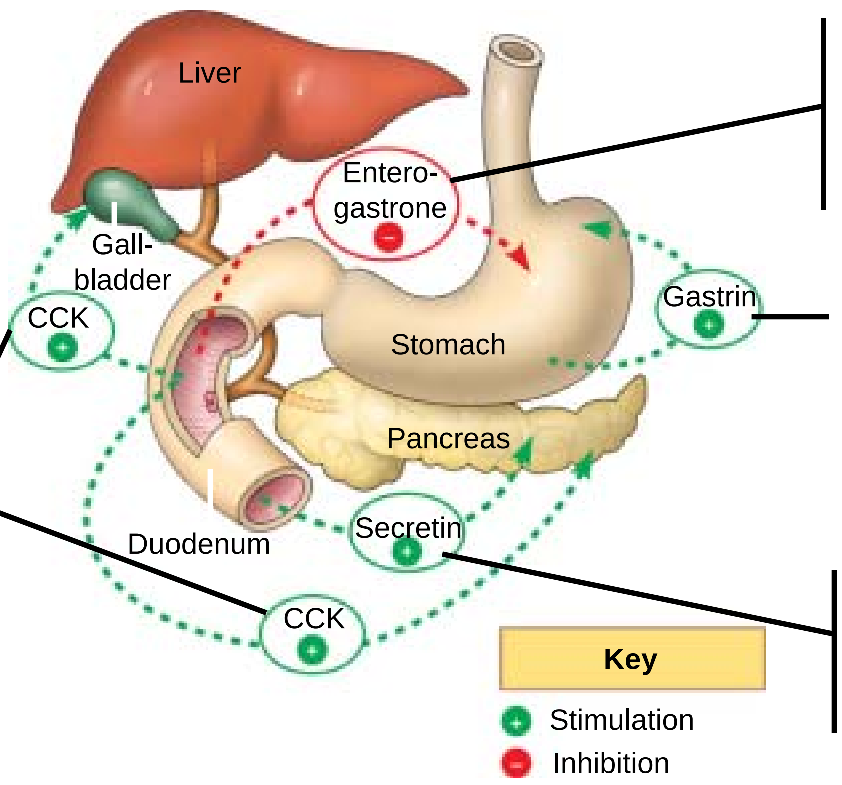
Hormones help regulate digestion

- Certain substances in food stimulate the stomach wall to release the hormone **gastrin** into the circulatory system.
  - As it recirculates, gastrin stimulates further secretion of gastric juice.
  - If the pH of the stomach contents becomes too low, the acid will inhibit the release of gastrin.
- Other hormones, collectively called **enterogastrones**, are secreted by the walls of the duodenum.

Enterogastrones

- **Secretin** which signals the pancreas to release bicarbonate to neutralize the chyme.
- **Cholecystokinin (CCK),** secreted in response to the presence of amino acids or fatty acids, causes the gallbladder to contract and release bile into the small intestine and triggers the release of pancreatic enzymes.

Hormonal control of digestion



Enterogastrone secreted by the duodenum inhibits peristalsis and acid secretion by the stomach, thereby slowing digestion when acid chyme rich in fats enters the duodenum.

Gastrin from the stomach recirculates via the bloodstream back to the stomach, where it stimulates the production of gastric juices.

Amino acids or fatty acids in the duodenum trigger the release of **cholecystokinin (CCK),** which stimulates the release of digestive enzymes from the pancreas and bile from the gallbladder.

Secreted by the duodenum, **secretin** stimulates the pancreas to release sodium bicarbonate, which neutralizes acid chyme from the stomach.

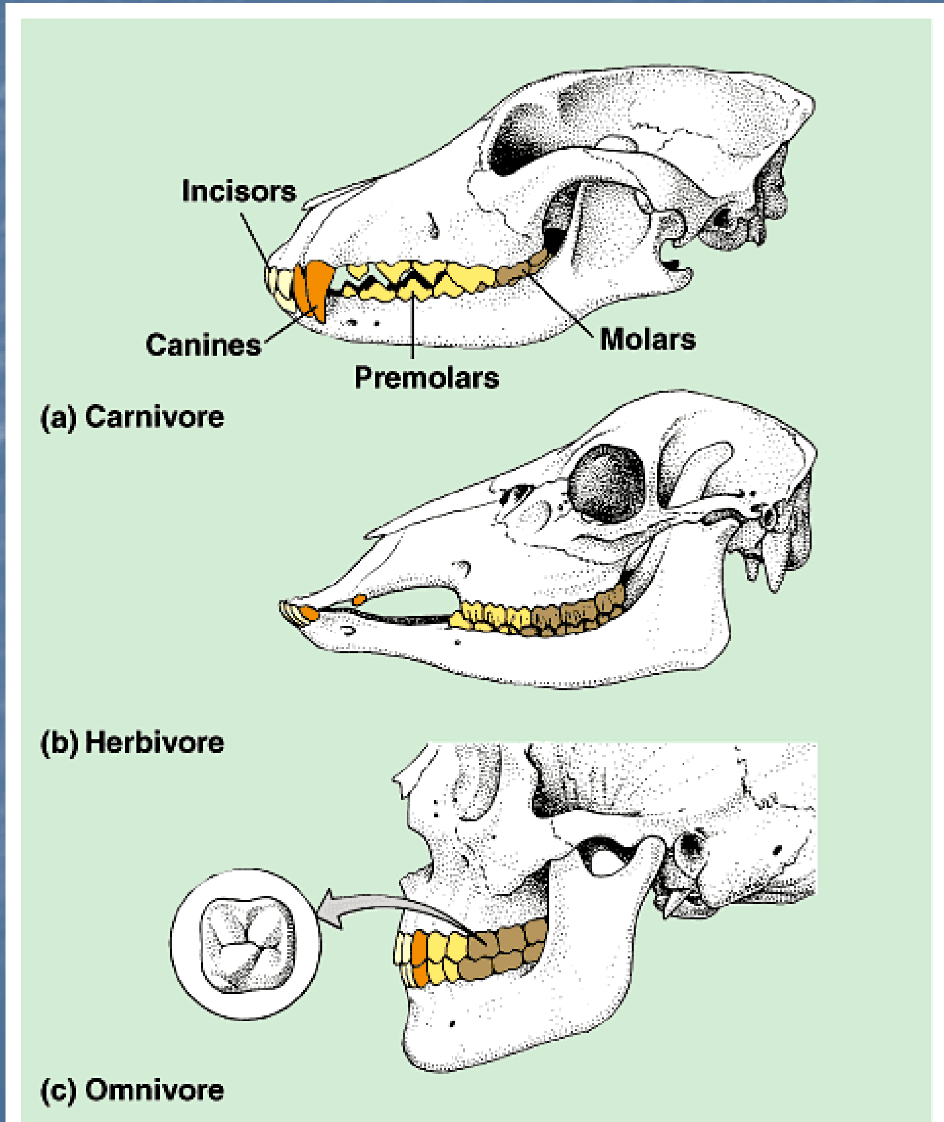
Colon

- The **large intestine**, or **colon**, is connected to the small intestine at a T-shaped junction where a sphincter controls the movement of materials.
  - One arm of the T is a pouch called the **cecum**.
- A major function of the colon is to recover water.
  - Over 90% of the water is reabsorbed, most in the the small intestine, the rest in the colon.
  - Digestive wastes, the **feces**, become more solid as they are moved along the colon by peristalsis.
- Living in the large intestine is a rich flora of mostly harmless bacteria.
  - One of the most common inhabitants of the human colon is *Escherichia coli*
- The terminal portion of the colon is called the **rectum**, where feces are stored until they can be eliminated.

Evolutionary Adaptations of Vertebrate Digestive Systems

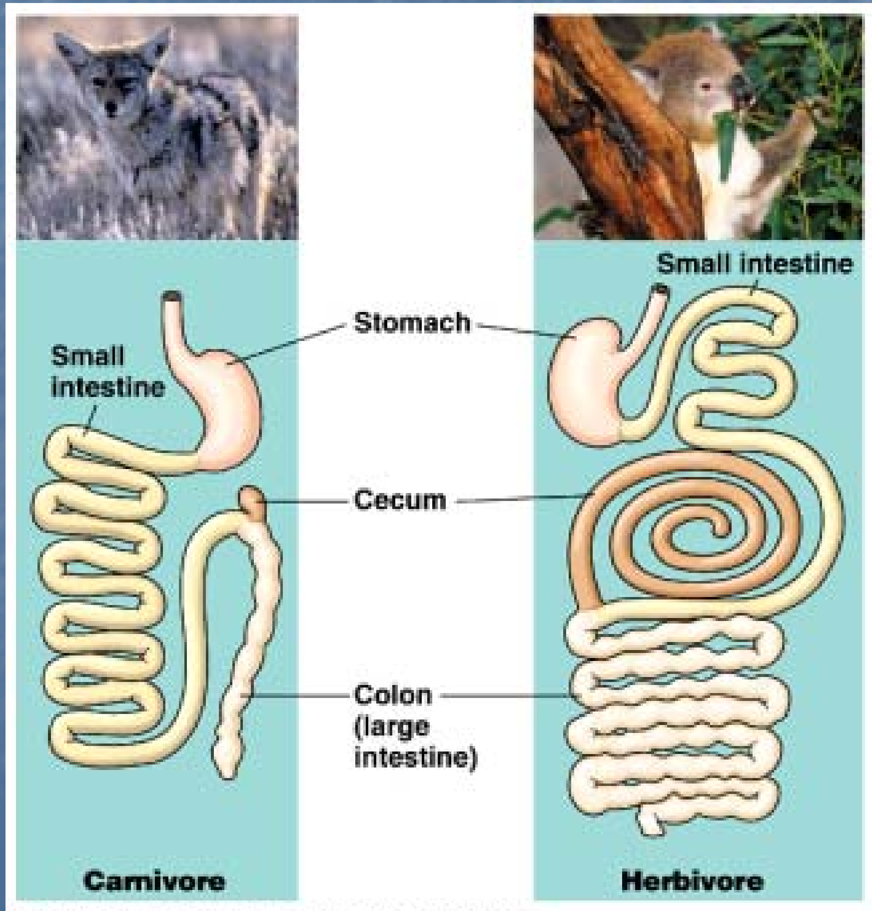
- **Structural adaptations of digestive systems are often associated with diet.**
- Dentition, an animal's assortment of teeth, is one example of structural variation reflecting diet.

Dental Adaptations



Stomach and Intestinal Adaptations

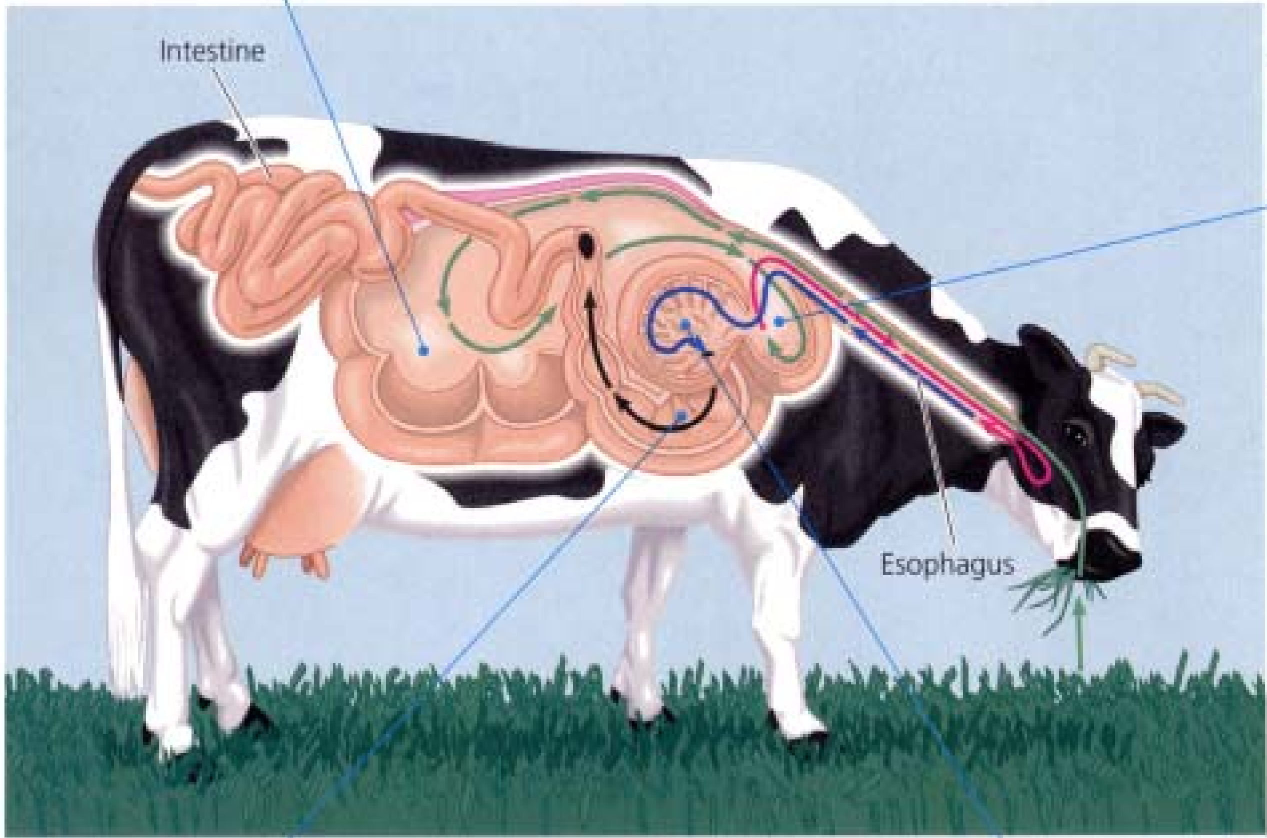
- The length of the vertebrate digestive system is also correlated with diet.



Symbiotic Adaptations

- Much of the chemical energy in the diet of herbivorous animals is contained in the cellulose of plant cell walls.
- The location of symbiotic microbes in herbivores' digestive tracts varies depending on the species.
- The most elaborate adaptations for a herbivorous diet have evolved in the **ruminants.**

1 Rumen. When the cow first chews and swallows a mouthful of grass, boluses (green arrows) enter the rumen.



2 Reticulum. Some boluses also enter the reticulum. In both the rumen and the reticulum, symbiotic prokaryotes and protists (mainly ciliates) go to work on the cellulose-rich meal. As by-products of their metabolism, the microorganisms secrete fatty acids. The cow periodically regurgitates and rechews the cud (red arrows), which further breaks down the fibers, making them more accessible to further microbial action.

3 Omasum. The cow then reswallows the cud (blue arrows), which moves to the omasum, where water is removed.

4 Abomasum. The cud, containing great numbers of microorganisms, finally passes to the abomasum for digestion by the cow's own enzymes (black arrows).