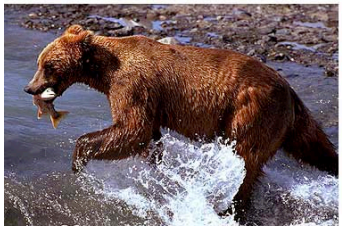
Chapter 41.

Animal Nutrition



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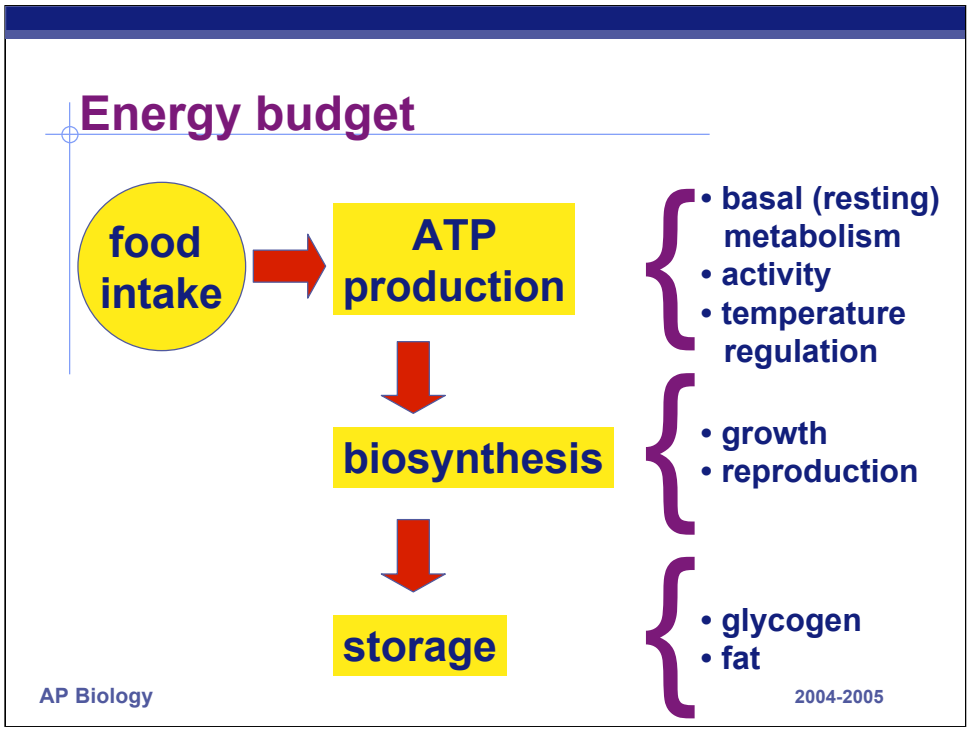
Nutritional requirements

- **Animals are heterotrophs**
  - need to take in food
  - nutritionally adequate diet fulfills 3 needs
    - fuel = chemical energy for cellular work
    - raw materials = carbon source for biosynthesis
    - essential nutrients = substances animals cannot make themselves




Energy budget
food intake
ATP production
biosynthesis
storage
• basal (resting) metabolism
• activity
• temperature regulation
• growth
• reproduction
• glycogen
• fat
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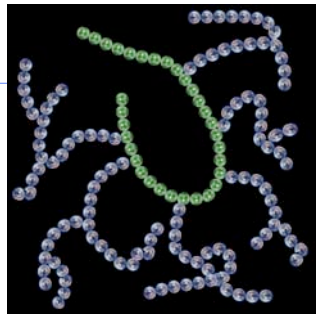
Energy budget

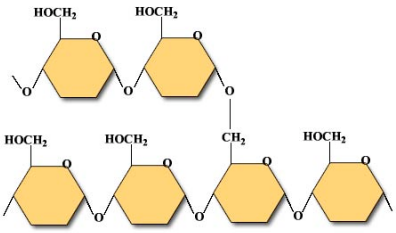
- The flow of food energy into & out of an animal can be viewed as a "budget"
  - animal takes in more calories than it needs to produce ATP
  - excess used for biosynthesis & storage
    - growth in size
    - reproduction
    - stored in energy depots

This obese mouse (L) has defect in gene which normally produces an appetite-regulating protein

Energy storage



- In humans
  - storage in liver & muscle cells
  - store as glycogen
    - polymer of many glucose units
- If glycogen stores full & caloric intake still exceeds caloric expenditure
  - excess stored as fat



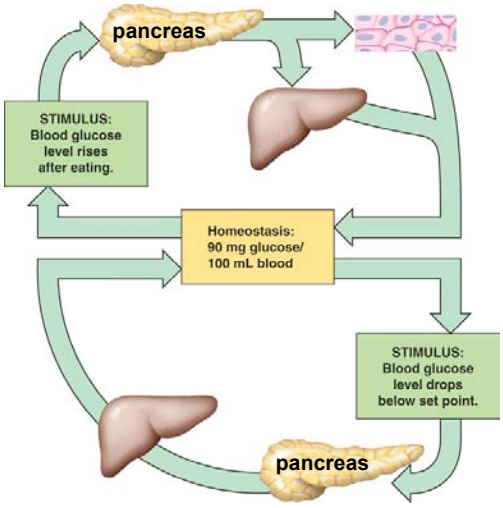
Managing caloric intake

- When fewer calories are taken in than are expended, fuel is taken out of storage depots & oxidized
  - breakdown glycogen from liver & muscle cells
  - metabolize fat



Homeostasis

- Balancing glucose levels in blood



Managing glucose levels

- human body regulates the use & storage of glucose, a major cellular fuel
  - insulin reduces blood glucose levels
    - when glucose levels rise above set point, pancreas secretes insulin
    - promotes transport of glucose into cells & storage of glucose as glycogen in liver & muscle cells
    - dropping blood glucose levels
  - glucagon increases blood glucose levels
    - when glucose levels drop below set point, pancreas secretes glucagon
    - promotes breakdown of glycogen & release of glucose into the blood
    - increasing blood glucose levels

Nutritional requirements

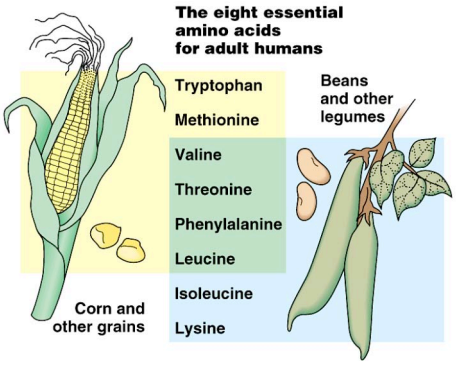
- Fuel for ATP production
- Raw materials for biosynthesis
  - source of N & P
    - to make complex molecules = proteins, nucleic acids
  - need complex molecules animals cannot synthesize
    - amino acids, vitamins
  - need minerals
    - iron, calcium, etc.

Many herbivores have diets deficient in mineral salts. Must find other sources = salt licks, chewing on bones

Vegetarian diets

- 8 essential amino acids
  - what about the other 12?
- Possible amino acid deficiency can be avoided by eating foods with complementary amino acids
  - beans & grains

What happens if diet is missing an essential nutrient?



Essential vitamins (coezymes)

Table 41.1 Vitamin Requirements of Humans: Water-Soluble Vitamins

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 Flushing of face and hands, 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 (also made by colon bacteria)	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; needed for 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 (e.g., 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

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Essential vitamins (coezymes)

Table 41.1 Vitamin Requirements of Humans: Fat-Soluble Vitamins

Vitamin	Major Dietary Sources	Some Major Functions in the Body	Possible Symptoms of Deficiency or Extreme Excess
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; needed for maintenance of epithelial tissues; antioxidant; helps prevent damage to lipids of 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 lipids of 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

Essential minerals (cofactors)

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

Dietary regimes

- All animals eat other organisms
  - Herbivores
    - eat mainly autotrophs (plants, algae)
    - gorillas, cows, hares, snails
  - Carnivores
    - eat other animals
    - sharks, hawks, spiders, snakes
  - Omnivores
    - consume animals & plants or algae
    - cockroaches, bears, raccoons, humans
    - humans evolved as hunters, scavengers & gatherers

Feeding adaptations

suspension feeding

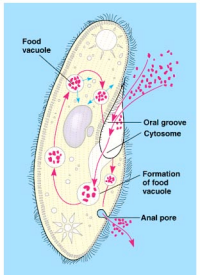
substrate feeding

fluid feeding

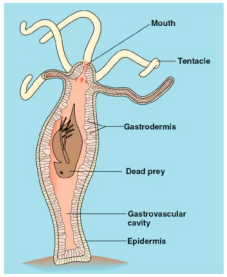
bulk feeding

Food processing

- **Ingestion**
  - eating
- **Digestion**
  - breaking food down into molecules small enough for the body to absorb
  - enzymatic hydrolysis
- **Absorption**
  - animal cells take up small molecules
- **Elimination**
  - undigested material passes of digestive system

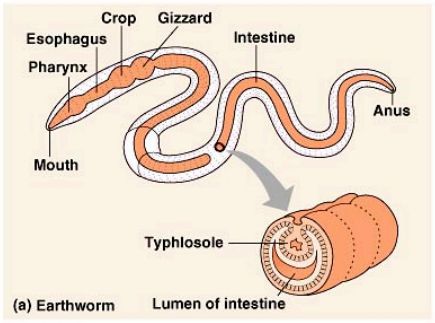


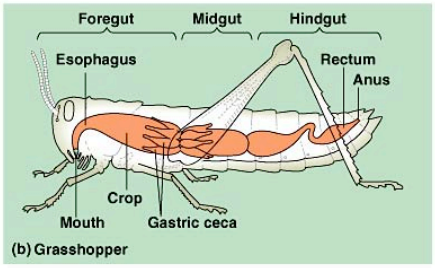
intracellular digestion

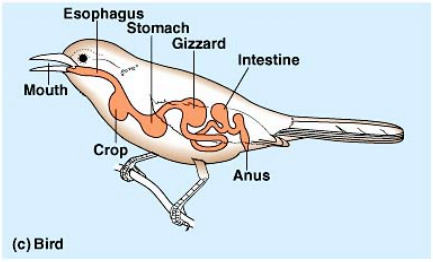


extracellular digestion

Digestive systems

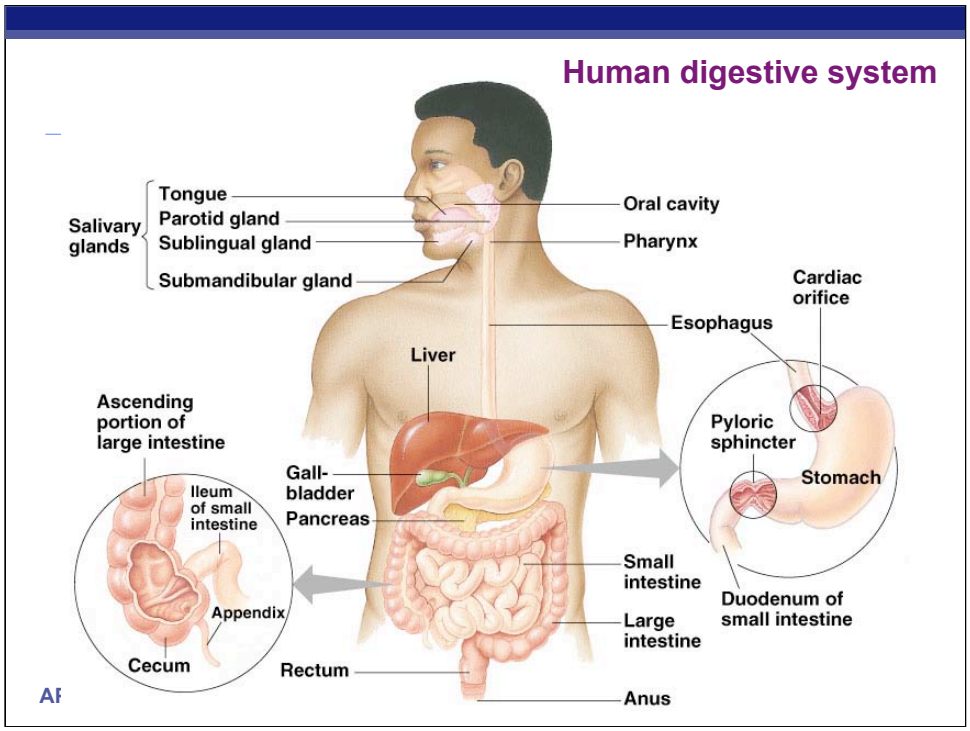






Mammalian digestive system

- Alimentary canal
  - peristalsis
    - rhythmic waves of contraction by smooth muscles in the walls of the canal, push food along
  - sphincters
    - muscular ring-like valves, regulate the passage of material between specialized chambers of the canal
- Accessory glands
  - secrete digestive juices
  - salivary glands, pancreas, liver & gallbladder

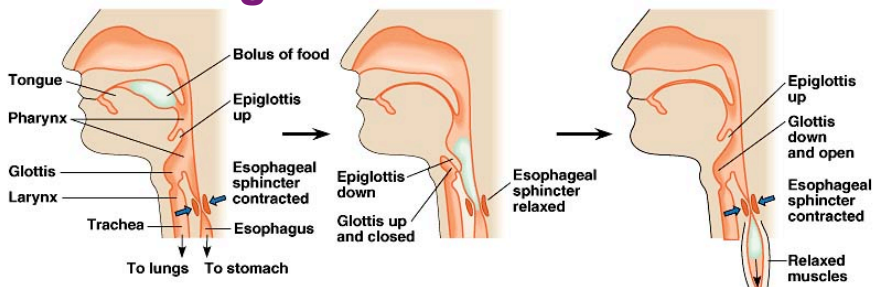


After chewing and swallowing, it takes 5 to 10 seconds for food to pass down the esophagus to the stomach, where it spends 2 to 6 hours being partially digested.

Final digestion and nutrient absorption occur in the small intestine over a period of 5 to 6 hours.

In 12 to 24 hours, any undigested material passes through the large intestine, and feces are expelled through the anus.

Swallowing



- **Mouth ingests**
  - mechanical digestion & chemical digestion of starch
- **Epiglottis**
  - closes trachea when swallowing
- **Esophagus**
  - moves food to stomach by peristalsis

Ingestion

- Mouth, pharynx & esophagus
  - physical & chemical digestion of food
  - trigger reflexive release of saliva from salivary glands, containing:
    - mucin
      - slippery glycoprotein
      - protects soft lining of mouth from abrasion & lubricates food for easier swallowing
    - buffers
      - help prevent tooth decay by neutralizing acid in mouth
    - antibacterial agents
      - kill bacteria that enter mouth with food
    - amylase
      - digests starch & glycogen

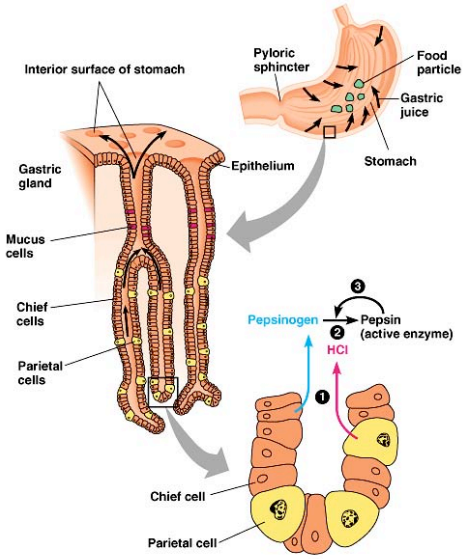
Throat

- **Pharynx**
  - junction that opens to both esophagus & trachea (windpipe)
  - swallowing
    - top of windpipe moves up so opening = glottis blocked by cartilaginous flap = epiglottis
    - ensures that bolus of food will be guided into entrance of esophagus & not directed down windpipe

Stomach

What keeps the stomach from digesting itself?

- **Food storage**
  - can stretch to fit ~2L food & fluid
- **Digestion**
  - gastric juice
    - digestive fluid secreted by epithelium lining stomach wall
    - HCl
      - pH 2
      - breaks down matrix that binds cells
      - kills bacteria
    - pepsin
      - breaks down proteins
    - mucus
      - protects stomach lining



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Still, the epithelium is continually eroded, and the epithelium is completely replaced by mitosis every three days.

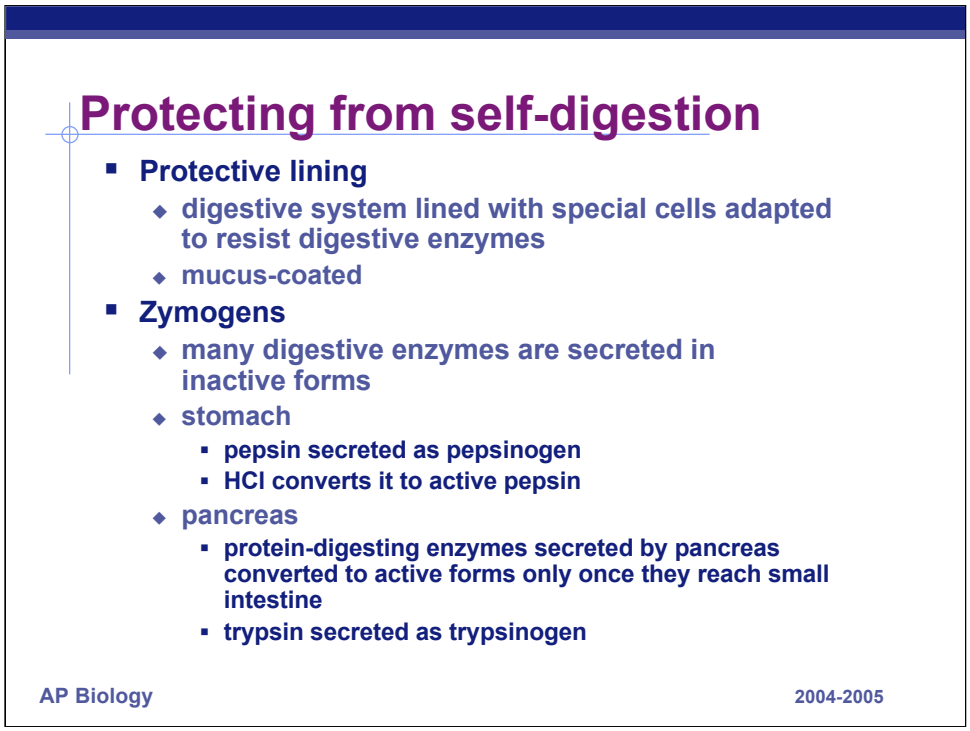
Gastric ulcers, lesions in the stomach lining, are caused by the acid-tolerant bacterium *Heliobacter pylori*.

Ulcers are often treated with antibiotics.

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 only when both reach the lumen of the stomach, minimizing self-digestion.

Also, in a positive-feedback system, activated pepsin can activate more pepsinogen molecules.



Body cells must be protected from protein digestive enzymes.

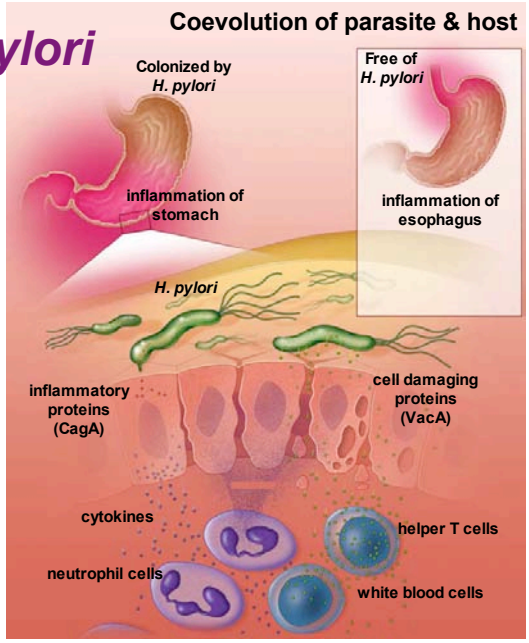
Many of the protein-digesting enzymes, such as aminopeptidase, are secreted by the intestinal epithelium, but trypsin, chymotrypsin, and carboxypeptidase are secreted in inactive form by the pancreas.

Another intestinal enzyme, **enteropeptidase**, converts inactive trypsinogen into active trypsin.

Active trypsin then activates the other two.

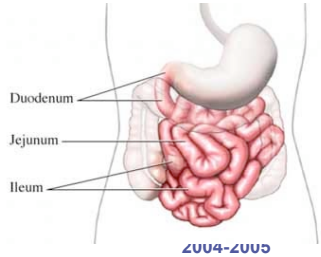
Helicobacter pylori

- **Bacteria-stomach feedback interactions**
  - ***H. pylori*** **bacteria colonize stomach**
  - **causes damaging inflammation to modify stomach's acidity**
  - **high rate of ulcer & stomach cancer**
  - **control with antibiotics**
  - **but new evidence that loss of H. pylori increases rates of esophageal cancers & acid reflux**



Small intestine

- **Major organ of digestion & absorption**
  - **over 6 meters!**
  - **3 sections**
    - **duodenum = most digestion**
    - **jejunum = absorption of nutrients & water**
    - **ileum = absorption of nutrients & water**
  - **absorption through lining of intestines**
    - **small intestine has huge surface area = 300 m^2 (roughly size of tennis court)**



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About every 20 seconds, the stomach contents are mixed by the churning action of smooth muscles.

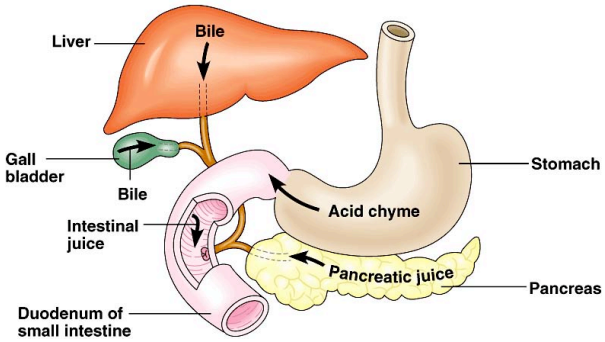
As a result of mixing and enzyme action, what begins in the stomach as a recently swallowed meal becomes a nutrient-rich broth known as **acid chyme**.

At the opening from the stomach to the small intestine is the **pyloric sphincter**, which helps regulate the passage of chyme into the intestine.

A squirt at a time, it takes about 2 to 6 hours after a meal for the stomach to empty.

Duodenum

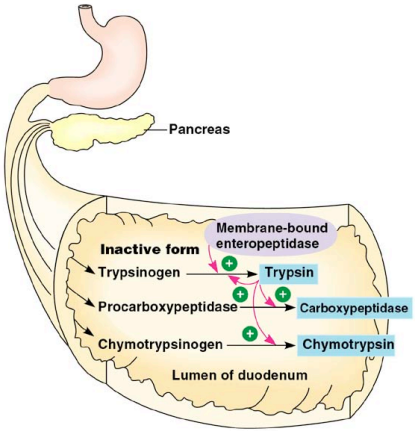
- Acid material from stomach mixes with digestive juices from:
  - pancreas, liver, gall bladder & glandular cells of intestinal wall



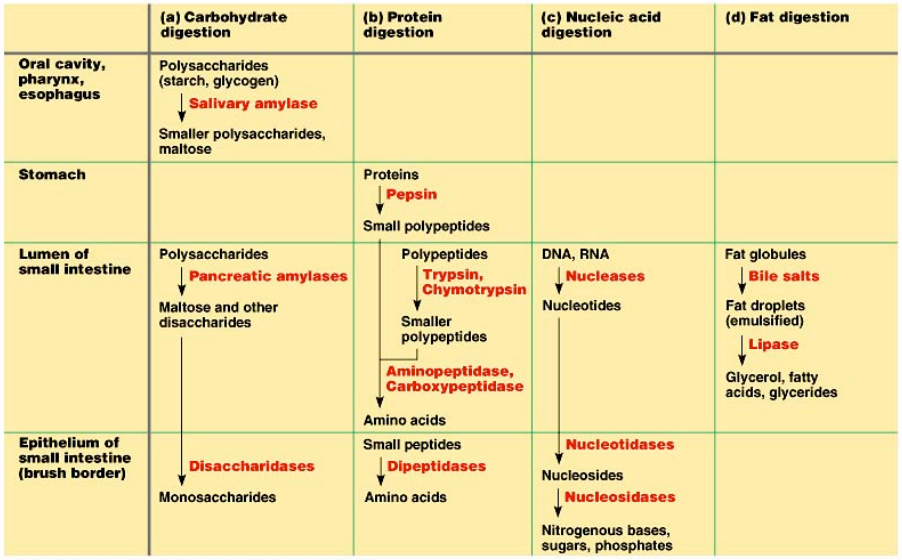
Pancreas

- Hydrolytic enzymes
  - peptidases
  - amylase
- Buffers
  - alkaline solution rich in bicarbonate = buffers acidity of material from stomach

What keeps the pancreas from digesting itself?

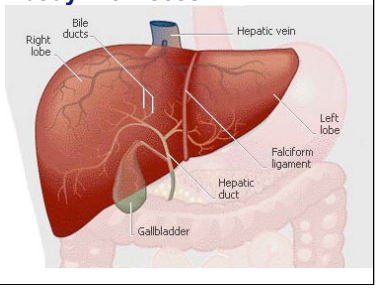


Explain how this is a molecular example of form follows function


(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)
Disaccharidases
Monosaccharides
Small peptides
Dipeptidases
Amino acids
Nucleotidases
Nucleosides
Nucleosidases
Nitrogenous bases, sugars, phosphates

Liver

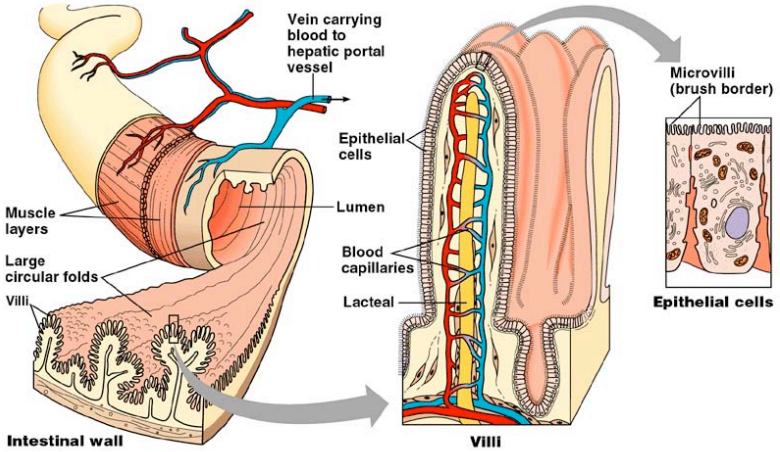
- many functions in body
  - digestive system = production of bile
  - bile stored in gallbladder until needed
  - contains bile salts which act as detergents
    - aid in digestion & absorption of fats
  - bile also contains pigments that are by-products of red blood cell destruction in liver
    - bile pigments are eliminated from body with feces
    - brown feces = rusty iron from hemoglobin!



Absorption

Explain how this is a structural example of form follows function

- Villi
  - increase surface area

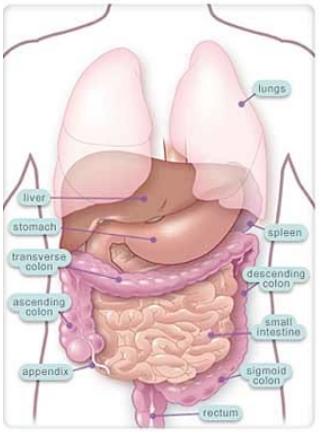


Absorption of Nutrients

- **Passive**
  - fructose
- **Active (protein pumps)**
  - amino acids, small peptides, vitamins & glucose are pumped against concentration gradients by epithelial membranes
  - allows intestine to absorb a much higher proportion of nutrients in the intestine than would be possible with passive diffusion

Large intestines (colon)

- Reclaiming water
  - used as solvent for various digestive juices
    - ~7L of fluid secreted into digestive tract daily
    - > 90% of water reabsorbed
      - diarrhea = insufficient water absorbed
      - constipation = too much water absorbed



Flora of large intestines

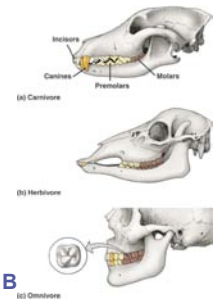
- Living in the large intestine is a rich flora of mostly harmless bacteria
  - *E. coli*, a favorite research organism
  - as a by-product of their metabolism, many colon bacteria generate gases, including methane & hydrogen sulfide
  - some bacteria produce vitamins
    - biotin, folic acid, vitamin K & several B vitamins

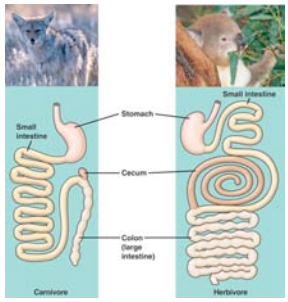
Rectum

- Terminal portion of colon
  - Feces contain
    - masses of bacteria
    - undigested materials, mainly cellulose
      - roughage or fiber
    - salts

Structural adaptations

- **Structural variations reflecting diet have made mammals very successful**
  - dentition
  - length of digestive system
  - number & size of stomachs





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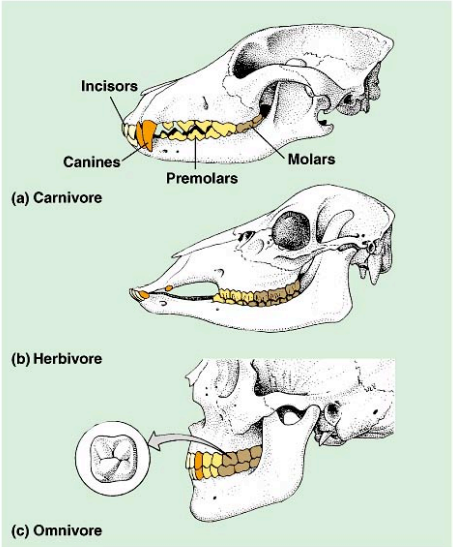
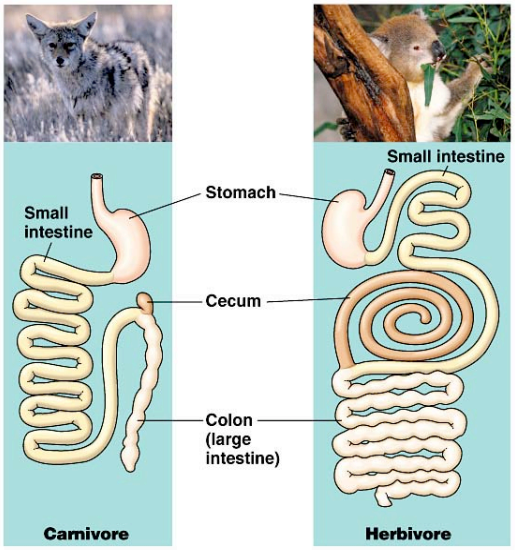
Dentition

- evolutionary adaptation of teeth for processing different kinds of food



Length of digestive system

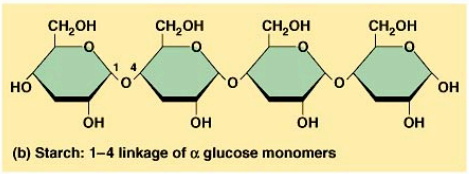
- **Herbivores & omnivores**
  - long digestive systems
  - harder to digest cellulose (cell walls)
- **Carnivores**
  - short digestive systems

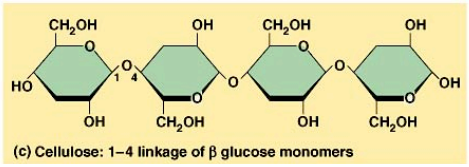


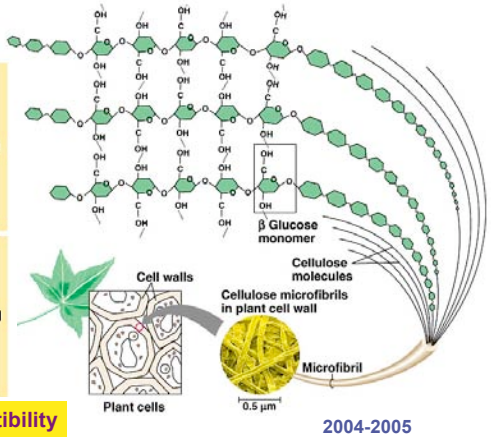
Digesting cellulose

- **How well you digest cellulose governs life strategy of herbivores**

starch vs. cellulose







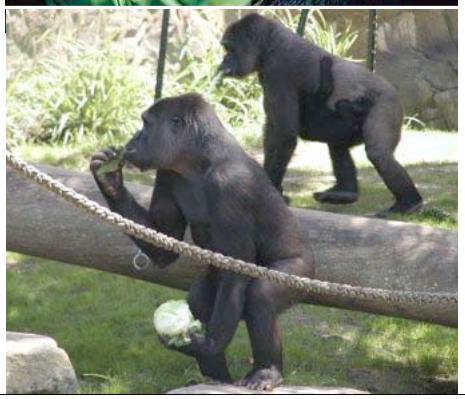
position of glycosidic linkage governs digestibility

Starch = all the glycosidic linkage are on same side = molecule lies flat

Cellulose = cross linking between OH (H bonds) = rigid structure & hard to digest

The digestion of cellulose governs the life strategy of herbivores.

1. Either you do it really well and you're a cow or an elephant (spend a long time digesting a lot of food with a little help from some microbes & have to walk around slowly for a long time carrying a lot of food in your stomach)
2. Or you do it inefficiently and have to supplement your diet with simple sugars, like fruit and nectar, and you're a gorilla.



Cow

- can digest cellulose well; no need to eat supplemental sugars

Gorilla

- can't digest cellulose well; must supplement with sugar source, like fruit

Symbiotic organisms

- How can cows digest cellulose efficiently?
  - symbiotic bacteria & protists help digest cellulose-rich meals of herbivores