







Why eat?

- **Macronutrients**
 - **Energy** for all our metabolic processes
 - **Monomers** to build our polymers
 1. Carbohydrates
 2. Lipids
 3. Protein
- **Micronutrients**
 - Tiny amounts of vital elements & compounds our body cannot adequately synthesize
 4. Vitamins
 5. Minerals
- **Hydration**
 6. Water

FEEDING

- "Eat": Gr. *-phagy*; Lt. *-vore*
- *Your food may not wish to be eaten!*
- DIET & MORPHOLOGY
- FOOD CAPTURE
- MECHANICAL PROCESSING




Never give up!


Niche: role played in a community (grazer, predator, scavenger, etc.)

- Some organisms have specialized niches so as to:
 - increase feeding efficiency
 - reduce competition
- **Optimal foraging model:** Need to maximize benefits (energy/nutrients) while minimizing costs (energy expended/risks)





Optimal Foraging Model







Optimal foraging strategies: Need to maximize benefits (energy/nutrients) while minimizing costs (energy expended / risks)

- Tapirs have 40x more meat, but are much harder to find and catch. So jaguars prefer armadillos.

Optimal Foraging Model

- Morphology reflects foraging strategies
- **Generalist** is less limited by rarity of resources
- **Specialist** is more efficient at exploiting a specific resource

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    graph TD
      A[OMNIVORE opossum] --> B[CARNIVORE wolf]
      A --> C[HERBIVORE elephant]
      B --> D[INSECTIVORE shrew]
      B --> E[PISCIVORE osprey]
      D --> F[MYRMECOPHAGORE anteater]
      style A stroke:#f00,stroke-width:2px
      style C stroke:#f00,stroke-width:2px
      style F stroke:#f00,stroke-width:2px
      style G[Generalist] stroke:#f00,stroke-width:2px
      style H[Specialist] stroke:#f00,stroke-width:2px
      A -.-> G
      F -.-> H
  
```

Feeding & Digestion

Anteater Adaptations

- Thick fur
- Small eyes
- Long claws in front
- Long snout
- Long barbed tongue
- No teeth

Bird Beaks

- Generalist & specialist bills

Types of bird bills

- Raven Generalized bill
- Cardinal Seed cracker
- American avocet Worm burrow probe
- Pelican Dip net
- Anhinga Fish spear
- Parrot Nut cracker
- Eagle Meat tearer
- Flamingo Mud sifter

FOOD CAPTURE SPECIALIZATIONS

- Fluid Feeding
- Suspension & Deposit Feeding
- Grazers & Browsers
- Predation: Ambush & Attraction
- Venoms
- Tool Use & Team Efforts

Fluid Feeding

- Sucking with tube
 - mosquitoes & butterflies
- Lapping with brushy tongue
 - hummingbirds, fruit bats
 - bees

Hummingbird tongue

- <http://www.youtube.com/watch?v=1wpQ8HQEkvE>

Suspension Feeding (Filter Feeding)

- Filter food (plankton, small animals, organic particles) suspended in water.
- Filters are hard, soft or even sticky.

Suspension and filter feeding

- A, Marine fan worms (class Polychaeta, phylum Annelida)
- B, Bivalve molluscs (class Bivalvia, phylum Mollusca)
- C, Barnacles (class Malacostraca, subphylum Crustacea, phylum Arthropoda)
- D, Herring and other suspension-feeding fishes (class Osteichthyes, phylum Chordata)
- E, Whalebone whales (class Mammalia, phylum Chordata)

Feeding & Digestion

Suspension Feeding (Filter Feeding)

- Barnacles: *“little shrimps that glue their heads to a rock and catch food with their feet”*

suspension feeding in baleen whales

suspension feeding in baleen whales

- Baleen is tough but flexible filter composed of the protein keratin.
- The length of the baleen depends upon the feeding style of the whale

Fig C-4. Baleen plates of different species of baleen whales. 10cm

Right Whales — “sippers”

- Skim feeding

Rorquals — “gulpers”

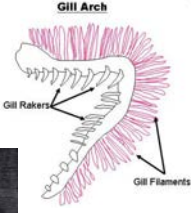
- Lunge feeding

Grey Whales — “mud suckers”

Feeding & Digestion

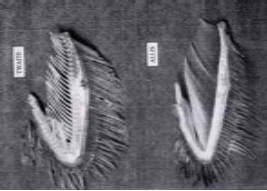
Suspension feeding in fish — gill rakers

- Raker spacing determines prey size.
 - If a habitat has two similar species, they diverge in gill raker spacing.
 - Reducing niche overlap is called **resource partitioning** or **niche divergence**.





Gill Arch
Gill Rakers
Gill Filaments

Two species of shad



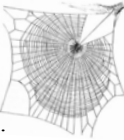
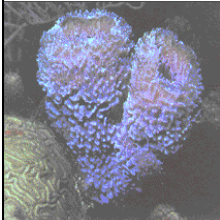
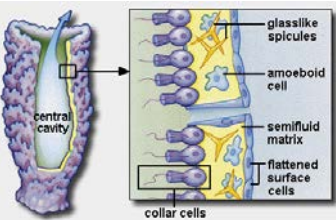
Suspension Feeding in extinct pterosaurs

- A pterosaur filters plankton in a lake

Sticky Filters

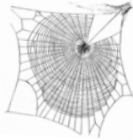

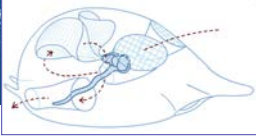
- Glue of spider webs
- Cnidocytes (stinging cells) of jellyfish.
- **Collar cells** of sponges

central cavity
collar cells
flattened surface cells
semifluid matrix
amoeboid cell
glasslike spicules

Sticky Filters

- Mucus nets
 - Larvaceans
 - Spoon worms & lug worms






Giant larvacean "house"


Deposit Feeders

- **Detritivores:** feed on decomposing particles & associated microorganisms deposited on/in sediment/soil

Sea cucumber mops detritus off sediment surface.





Earthworms swallow & digest organic material in soil as they burrow.





Grazers & Browsers

- **Grazers:** feed on fast growing, abundant, short vegetation (terrestrial grasses; aquatic turf algae) or encrusting animals
 - Slow moving, methodical
 - Mouth-parts for cropping or scraping food close to substrate
 - Grasses low moisture content: need water to drink



Feeding & Digestion

Grazers & Browsers



- **Browsers:** feed on taller vegetation (leaves, bark, etc.)
 - More selective; more mobile to locate patches
 - Food moisture may be adequate
 - More anti-herbivore defenses (thorns, toxins, etc.)

Grazers & Browsers



White Rhino (Broad-mouthed Rhino)	Black Rhino (Hooked-lip Rhino)
	
<p>Larger than black rhino. Large bulls reaching weights of 2500 kg.</p> <p>Grazer: have a broad flat mouth which aids in feeding off large quantities of grass</p> <p>Head posture faces downward so its mouth is always close to the ground while grazing.</p>	<p>Smaller than the white rhino. A large bull weighs around 1000 kg.</p> <p>Browser: have a small hooked shaped mouth for feeding on trees and shrubs</p> <p>Head posture is face upward, so there is no need for it to lift its head when feeding off trees.</p>

Ambush Predators

- Crab & trap door spiders, Komodo dragons, lions, etc.
- Works best if animal has **cryptic coloration.**

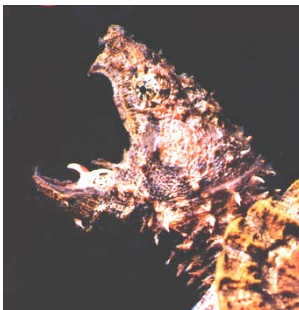
Ensnare Prey

- Bolas spiders snag 'em, onychophorans slime 'em.


Attraction

- **Chemical Lures**
 - bolas spider mimics female moth pheromone
- **Visual Lures**
 - Fireflies
 - Snapping turtles
 - Angler fish



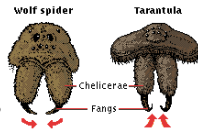
Toxins

- Poison saliva is used by shrews & cephalopods



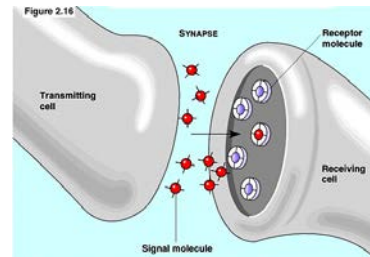
Inject Toxins (Venom)

- Fangs: spiders or snakes
- Stingers: wasps and scorpions



Neurotoxins Immobilize Prey

- Block neurotransmitters that control movement.
- Prevent escape and/or harm to predator.



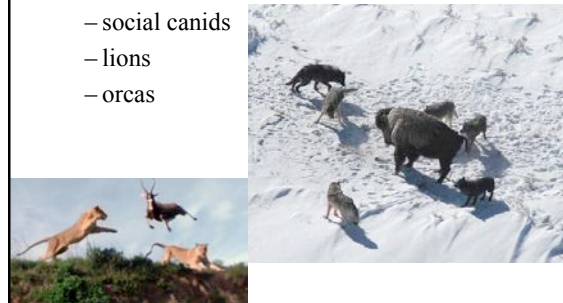
Tissue-destructive Toxins Digest Prey



- Scorpions & spiders have external digestion.
- Rattlesnakes consume VERY large prey.

Team Efforts

- Team up to capture larger/faster prey
 - social canids
 - lions
 - orcas



Tool Use

- Galapagos finches, ravens, & Egyptian vultures
- Chimps & sea otters



Digestion

- The hydrolysis (breakdown) of large food molecules (polymers) into small organic subunits (monomers).
- The monomers may then be used for:
 - Metabolic fuel (cellular respiration → ATP & heat)
 - or
 - Subunits to build new polymers
- **Hydrolysis is catalyzed by enzymes**
 - May be intracellular or extracellular

Hydrolytic Enzymes

- Hydrolysis reactions catalyzed by enzymes
– enzyme names end with “-ase”
- **Amylase**: hydrolyze carbohydrates
- **Protease**: hydrolyze proteins
- **Peptidase**: hydrolyze peptides
- **Lipase**: hydrolyze lipids

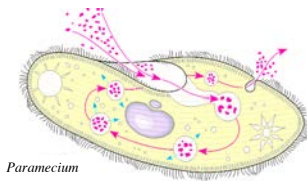
Hydrolytic Enzymes

- Most plant material is largely cellulose
- Yet no animal has enzymes that can digest cellulose
- Most herbivores depend upon symbioses with **cellulytic protists** in their guts
- In turn, the cellulytic protists depend upon symbioses with bacteria to produce the actual enzymes

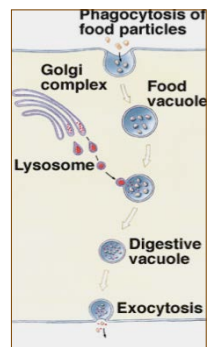


Intracellular Digestion

1. phagocytosis
2. ⇒ food held in vacuole
3. ⇒ vacuole fuses with lysosome filled with digestive enzymes
4. ⇒ food digested
5. ⇒ exocytosis of indigestible material

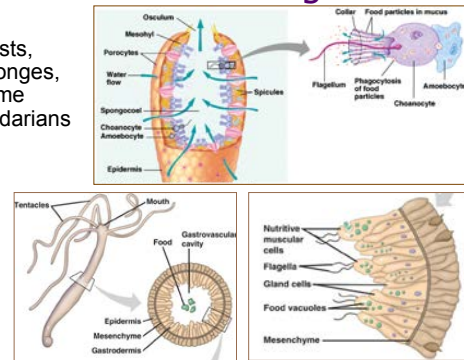


Paramecium



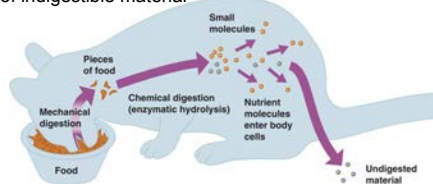
Intracellular Digestion

Protists, sponges, some cnidarians



Extracellular Digestion

1. enzymes secreted into space (lumen of digestive tract)
2. ⇒ food broken into small molecules
3. ⇒ absorption by cells lining the digestive tract
4. expulsion of indigestible material



Internal Digestion & Food Processing

1. Ingestion
– Consuming food
2. Physical disruption
– Mastication, dissolution, denaturation, emulsification
3. Motility
– Swallowing, peristalsis, segmentation, defecation
4. True digestion
– Hydrolysis of polymers into monomers
5. Absorption
– Moving nutrients from G.I. Tract into circulatory system
6. Assimilation
– Incorporate nutrient molecules into tissues


Feeding & Digestion

Ingestion for Internal Digestion

1. Ciliary (or flagellar) motility
2. Oral appendages
 - a. Ciliary
 - b. Grasping / Sweeping
3. Protrusible / prehensile structures
 - a. Pharynx
 - b. Jaws
4. Swallowing
 - a. Ram / Gravity / Lunge / Suction
 - b. Pharyngeal / Ratcheting jaws
 - c. Lingual

Ingestion for Internal Digestion

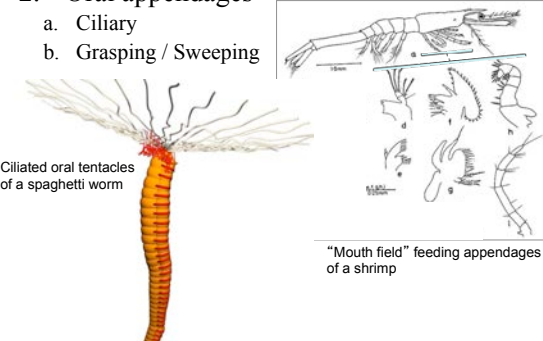
1. Ciliary (or flagellar) motility



Ctenophore
iridescent comb rows [ctenes] of ciliated plates for both propulsion & feeding currents
<https://www.youtube.com/watch?v=GGFr0WD2IYA>

Ingestion for Internal Digestion

2. Oral appendages
 - a. Ciliary
 - b. Grasping / Sweeping

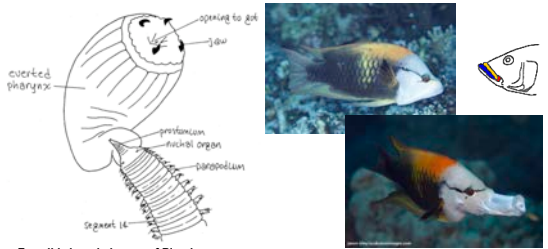


Ciliated oral tentacles of a spaghetti worm

"Mouth field" feeding appendages of a shrimp

Ingestion for Internal Digestion

3. Protrusible / prehensile structures
 - a. Pharynx
 - b. Jaws




Eversible jawed pharynx of Bloodworm
<https://www.youtube.com/watch?v=mkfMxLn8rA>

Slingjaw wrasse
<https://www.youtube.com/watch?v=pD4CQWxANy>

Ingestion for Internal Digestion

4. Swallowing
 - a. Ram / Gravity / Lunge / Suction



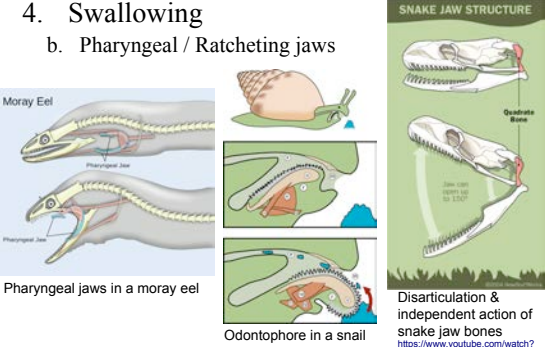
Lunge & gravity swallowing by Blue heron
<https://www.youtube.com/watch?v=1-g2A9uT80>

Suction feeding by Cichlid
<https://www.youtube.com/watch?v=TbGIL8p5Y8>

Suction feeding by Tiger fish
<https://www.youtube.com/watch?v=m2cBaqYK1o>

Ingestion for Internal Digestion

4. Swallowing
 - b. Pharyngeal / Ratcheting jaws



Pharyngeal jaws in a moray eel

Odontophore in a snail

Snake Jaw Structure


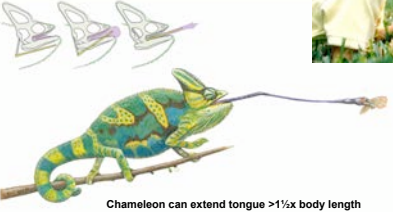
Disarticulation & independent action of snake jaw bones
https://www.youtube.com/watch?v=HP80cr3K_jho

Ingestion for Internal Digestion

4. Swallowing

c. Lingual

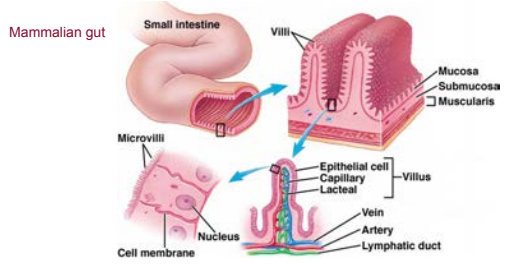
- Tongue of most vertebrates
 - Intrinsic muscles — *hydrostat*
 - Extrinsic muscles — anchoring

Chameleon can extend tongue >1½x body length
<https://www.youtube.com/watch?v=YXboRU4k30E>

Internal Digestion — Digestive Tracts

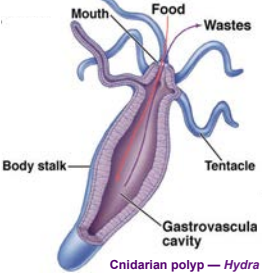
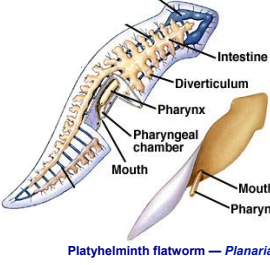
- Epithelial tissue lining a hollow cavity (**lumen**)
- Ridges & wrinkles to increase surface area for absorption
- Usually highly vascularized to transport absorbed materials



Mammalian gut

Digestive Tracts

- **Gastrovascular systems (blind guts)**
 - indigestible material regurgitated

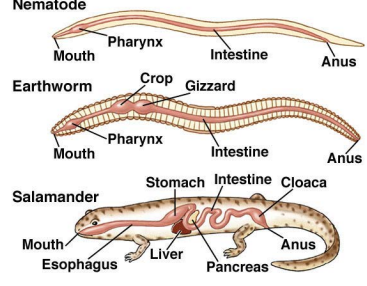



Cnidarian polyp — *Hydra*

Platyhelminth flatworm — *Planaria*

Digestive Tracts

- **Complete guts**
 - Mouth ⇒ Anus



Nematode

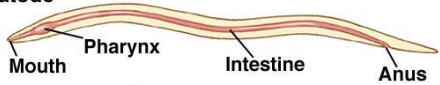
Earthworm

Salamander

Digestive Tracts

- **Complete guts**
 - Mouth ⇒ Anus

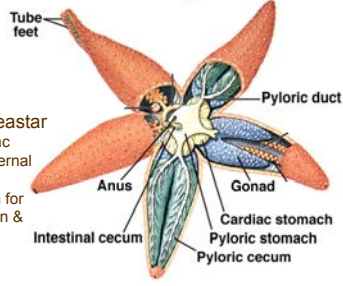
Nematode



- Muscular pharynx pushes food through non-muscular gut
- Free-living roundworms feed on microbes
- Parasitic roundworms feed on host body fluids
- No need for much specialization of gut

Digestive Tracts

- **Complete guts**
 - Mouth ⇒ Anus



Echinoderm seastar

- Eversible cardiac stomach for external digestion
- Pyloric stomach for internal digestion & absorption

Feeding & Digestion

Digestive Tracts

- **Complete guts**
 - Mouth ⇒ Anus

typhlosole
intestine

Annelid earthworm

- Dorsol **typhlosole** increases surface area adjacent to dorsal heart vessel

Digestive Tracts

- **Complete guts**
 - Mouth ⇒ Anus

Foregut Midgut Hindgut
Esophagus Mouth Crop Gastric ceca Rectum Anus

(b) Grasshopper

Insect grasshopper

- Gastric ceca allow fermentation of plant material

Digestive Tracts

Vertebrate and invertebrate digestion

RECEPTION: Mouth parts, salivary glands
CONDUCTION: Esophagus
STORAGE AND EARLY DIGESTION: Stomach (vertebrates) crop (insects, birds)
GRINDING: Gizzard (birds) proventriculus (insects)
TERMINAL DIGESTION AND ABSORPTION: Small intestine (vertebrates) midgut (insects)
WATER ABSORPTION, CONCENTRATION OF SOLIDS: Large intestine (vertebrates) hindgut (insects)

Pancreas Cecum

Vertebrate Insect

Insects & Vertebrates

- Gut divisions into specialized regions allows more efficient digestion & exploitation of more food types

Digestive Tracts

Mouth Esophagus Stomach Gizzard Intestine Anus

Digestion in Birds

Vertebrate — birds

- Anus empties into cloaca
 - common terminal chamber for digestive, excretory & reproductive systems
- Cloaca empties via vent

Internal Digestion & Food Processing

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 - Hydrolysis of polymers into monomers
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 - Moving nutrients from G.I. Tract into circulatory system
6. Assimilation
 - Incorporate nutrient molecules into tissues

Mastication — physical disruption of food particles

- Small particles are more easily broken down by digestive enzymes
 - Chewing ↑ Surface to Volume (S/V) Ratio of particles
∴ ↑ exposure to enzymes

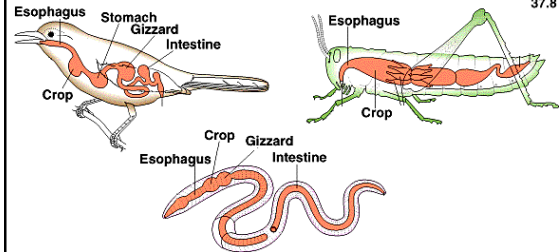
ORAL MASTICATION

- **Beaks** in birds, turtles, & cephalopods
- **Teeth** in vertebrates
- **Mandibles** in insects
- **Radula** in most molluscs



Gastric Mills of Arthropods, Birds and Earthworms

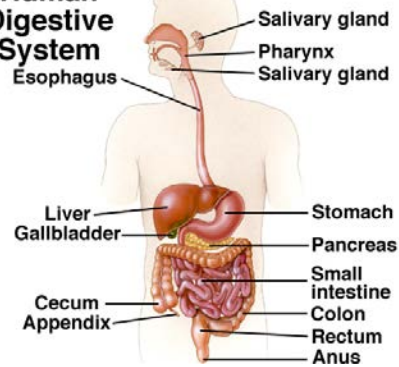
- Storage **crop** leads to grinding **gizzard** - a muscled sac w/ a hard lining to grind foods w/ sand, pebbles.



Vertebrate Digestive System

- Alimentary Canal (humans: 26-foot long tube)
 - Mouth
 - Pharynx
 - Esophagus
 - gastrointestinal [G.I.] tract ("gut")
 - Stomach
 - Small Intestine
 - Large Intestine
- Accessory Organs
 - Salivary Glands
 - Liver & Gall Bladder
 - Pancreas

Human Digestive System



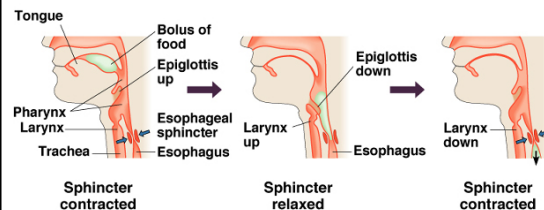
Digestion Begins in Mouth



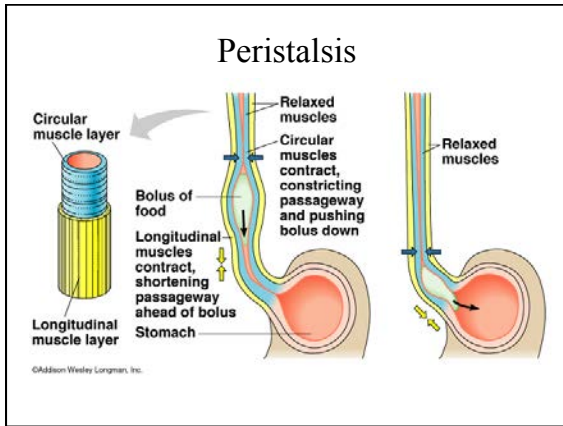
- Salivary glands produce **Amylase**
 - Enzyme hydrolyzes starch
 - Cleans teeth
- Saliva also contains mucous, buffers, antibacterials
- Slug of mashed food and saliva is a **Bolus**

Swallowing

- Salivary glands
 - Water & mucus: moisten/lubricate food
- Pharynx
 - Initiate swallowing reflex
 - Divert food bolus from respiratory tract
- Esophagus
 - uses peristaltic action



Feeding & Digestion



Gut Motility

- Peristalsis** — waves of involuntary muscle contraction
 - Esophagus, stomach, small intestines
- Segmentation** — churning action
 - Stomach, small intestines
- Sphincters** — muscular rings that control entry/exit
 - Esophageal sphincter
 - Pyloric sphincter
 - Anal sphincter

esophagus

muscles constricted

food

peristaltic wave of contraction

muscles relaxed

muscles constricted

food

stomach

peristalsis

segmentation movements

chyme

segmentation movements

small intestine

to large intestine

Muscular action in the human gut

Stomach

- Distensible: stores swallowed food pending further processing. Sealed by sphincters at either end.
- Mucosa wrinkled to form rugae that increase surface area
- Highly motile. Regulates rate of passage to intestines.
- Many gastric pits leading to gastric glands secreting gastric juice
- Masticated food + digestive juices = **chyme**
- Acid in gastric juice disinfects the chyme

Esophagus

Cardia

Fundus

Body

Gastric rugae

Pylorus

Duodenum

Pyloric sphincter

Mucosa

Submucosa

Gastric Glands

Interior surface of stomach

Pits

Epithelium

Mucous cells

Chief cells

Parietal cells

Pepsinogen

HCl

Pepsin (active enzyme)

Pyloric sphincter

STOMACH

Gastric gland

Gastric Juice:

- Goblet cells ⇒ alkaline mucus
 - Helps protect mucosa from auto-digestion.
- Parietal cells ⇒ hydrochloric acid [HCl] ⇒ pH < 2
 - Disinfects chyme; denatures protein
- Chief cells ⇒ pepsinogen (a weak protease)
 - Auto-hydrolyzes to form pepsin (stronger protease)
- Other cells produce hormones

Protein Digestion Begins in the Stomach

1. Acid **denatures** protein in the chyme
 - Unfolded protein structure more vulnerable to hydrolysis
2. Pepsin **hydrolyzes** polypeptides into oligopeptide fragments
3. Digestion and absorption completed in small intestines

Lumen of stomach

Ingested protein

Short peptides

Pepsinogen

HCl

Pepsin

Gastric mucosa

Regulation of Gastric Activity

Table 18.6 The Three Phases of Gastric Secretion

Phase of Regulation	Description
Cephalic Phase	1. Sight, smell, and taste of food cause stimulation of vagus nuclei in brain
	2. Vagus stimulates acid secretion <ol style="list-style-type: none"> a. Direct stimulation of parietal cells (major effect) b. Stimulation of gastrin secretion (lesser effect)
Gastric Phase	1. Distension of stomach stimulates vagus nerve; vagus stimulates acid secretion <ol style="list-style-type: none"> a. Direct stimulation of parietal cells (lesser effect) b. Stimulation of gastrin secretion; gastrin stimulates acid secretion (major effect)
	2. Amino acids and peptides in stomach lumen stimulate acid secretion <ol style="list-style-type: none"> a. Direct stimulation of parietal cells (lesser effect) b. Stimulation of gastrin secretion; gastrin stimulates acid secretion (major effect)
	3. Gastrin secretion inhibited when pH of gastric juice falls below 2.5
Intestinal Phase	1. Neural inhibition of gastric emptying and acid secretion <ol style="list-style-type: none"> a. Arrival of chyme in duodenum causes distension, increase in osmotic pressure b. These stimuli activate a neural reflex that inhibits gastric activity
	2. In response to fat in chyme, duodenum secretes a hormone that inhibits gastric acid secretion

Gastric epithelium

Vagus nerve

Amino acids

Gastrin

Systemic circulation

Stomach lumen

G cell

ECL cell

Histamine

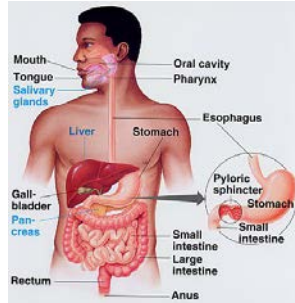
HCl

Parietal cell

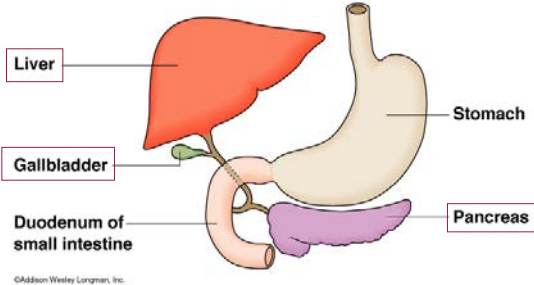
- Gastric secretion and motility stimulated by parasympathetic neurons, intrinsic stretch reflex, gastrin hormone, and amino acids in chyme (positive feedback amplification).
- Inhibited by stretch reflex and hormones from intestines, or chyme pH < 1.5.

Digestion Completed in Small Intestine

- Chyme enters via the pyloric sphincter.
- First segment = duodenum: secretions from accessory glands enter via common bile duct.
- First 40% = duodenum + jejunum: most digestion and absorption of macro- & micronutrients.
- Final 60% = ileum: most absorption/reabsorption of water and salts.



Visceral Digestive Accessory Glands



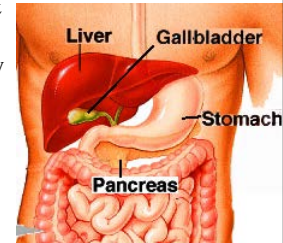
Liver: the biochemistry lab

Functional Category	Actions
Detection of Blood	Phagocytosis by Kupfer cells Chemical alteration of biologically active molecules (hormones and drugs) Production of urea, uric acid, and other molecules that are less toxic than parent compounds Excretion of molecules in bile
Carbohydrate Metabolism	Conversion of blood glucose to glycogen and fat Production of glucose from liver glycogen and from other molecules (amino acids, lactic acid) by gluconeogenesis Secretion of glucose into the blood
Lipid Metabolism	Synthesis of triglycerides and cholesterol Secretion of cholesterol in bile Production of ketone bodies from fatty acids
Protein Synthesis	Production of albumin Production of plasma transport proteins Production of clotting factors (fibrinogen, prothrombin, and others) Synthesis of bile salts Conjugation and excretion of bile pigment (bilirubin)

Table 18.3 Major Categories of Liver Function

Liver to Gall Bladder: *Bile Salts: Fat Emulsifier*

- Liver produces **bile salts & pigments**.
- Bile is stored & released by Gall Bladder into Small Intestine.
- Emulsify: Bile salts break large fat globs into small droplets (detergent action).



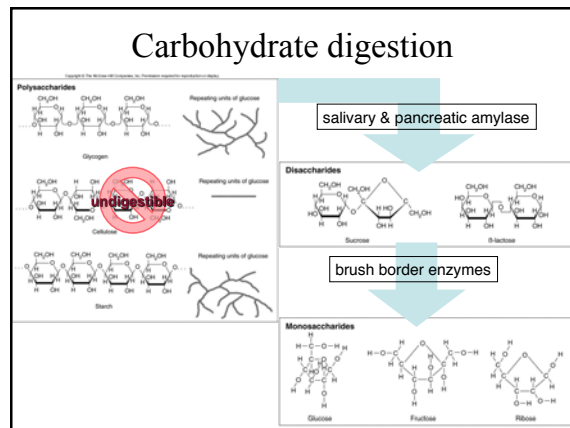
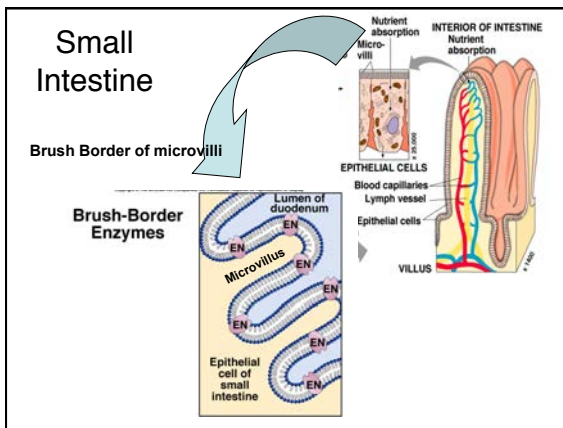
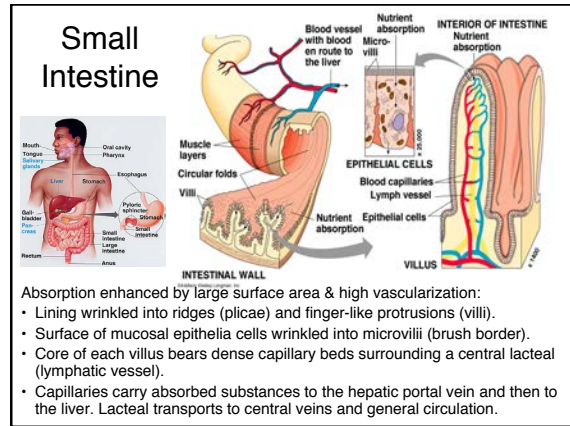
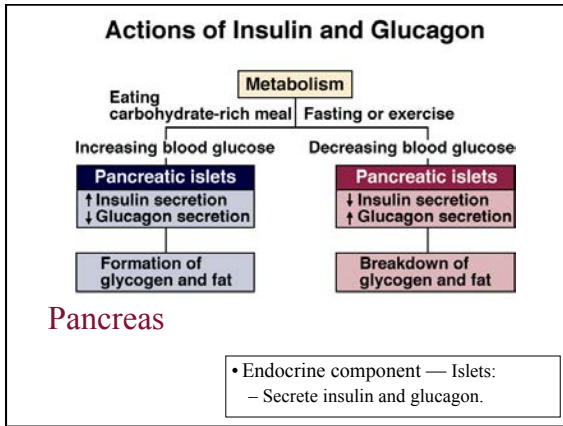
Fatty chyme entering the duodenum

CCK stimulates muscular layer of gallbladder wall to contract
 Bile passes down the cystic duct and common bile duct to duodenum
 Hepatopancreatic sphincter relaxes and bile enters duodenum
 Cells from the intestinal mucosa secrete the hormone cholecystokinin (CCK) into the bloodstream
 Hormonal signals released into bloodstream
 Stimulation of effector organ

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Hepatic ducts
 Cystic duct
 Common bile duct
 Gallbladder
 Duodenal papilla
 Duodenum
 Pancreatic acinus
 Pancreatic islet (of Langerhans)
 Pancreatic juice
 Pancreas
 Pancreatic duct

- Exocrine component — Acini:
 - Secrete pancreatic juice.
 - Bicarbonate to neutralize acid chyme
 - Suite of hydrolytic enzymes
- Endocrine component — Islets:
 - Secrete insulin and glucagon.



Carbohydrate Digestion — Summary

- Hydrolysis of polysaccharides (poly-glucose) starts with **salivary amylase**.
 - Minor significance — amylase denatured by gastric acid.
- Pancreatic amylase** in duodenum & jejunum hydrolyzes polysaccharides into maltose & maltotriose.
- Brush border enzymes** hydrolyze tri-/disaccharides into monosaccharides.
- Brush border transporters** absorb monosaccharides by active cotransport into hepatic portal vein.
- Insulin dependent: monosaccharides taken up by liver for glycogenesis, or circulate as energy substrate for glycolysis or lipogenesis.

Protein Digestion — Summary

- Proteins are denatured by gastric **acid** in stomach.
- Hydrolysis of exposed polypeptides starts with **pepsin** in gastric juice under acidic pH.
- Pancreatic proteases & peptidases**, plus **brush border peptidases** in duodenum & jejunum hydrolyze poly-/oligopeptides into tri-/dipeptides & amino acids.
- Brush border transporters** absorb tri-/dipeptides & amino acids into mucosal epithelia. **Intracellular peptidases** hydrolyze tri-/dipeptides into amino acids. Amino acids absorbed into hepatic portal vein.
- Insulin dependent: amino acids taken up by liver for gluconeogenesis, or circulate as substrate for protein synthesis

Lipid Digestion — Summary

1. Fats & oils are *emulsified* by **bile salts** (detergent) in duodenum & jejunum .
2. **Pancreatic lipases** in duodenum & jejunum hydrolyze triglycerides into monoglycerides & fatty acids.
3. Monoglycerides & fatty acids, plus cholesterol, coalesce with **bile salts** to form micelles.
4. **Brush border transporters** absorb micelles into mucosal epithelia. **Intracellular liposynthases** condense monoglycerides & fatty acids into new triglycerides. Triglycerides & cholesterol are bound to carrier proteins to form **chylomicron** lipoprotein.
5. Chylomicrons are absorbed into the lacteal and systemic circulation. **Lipoprotein-lipase** of vessel endothelia releases fatty acids & glycerol for tissue lipogenesis.

Absorption/Assimilation of Lipids

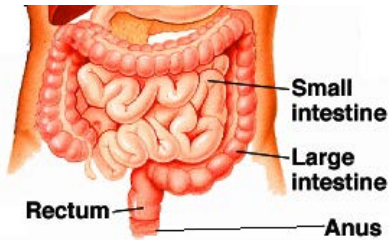
Table 18.8 Characteristics of the Lipid Carrier Proteins (Lipoproteins) Found in Plasma

Lipoprotein Class	Origin	Destination	Major Lipids	Functions
Chylomicrons	Intestine	Many organs	Triglycerides, other lipids	Deliver lipids of dietary origin to body cells
Very-low-density lipoproteins (VLDLs)	Liver	Many organs	Triglycerides, cholesterol	Deliver endogenously produced triglycerides to body cells
Low-density lipoproteins (LDLs)	Intracellular removal of triglycerides from VLDLs	Blood vessels, liver	Cholesterol	Deliver endogenously produced cholesterol to various organs
High-density lipoproteins (HDLs)	Liver and several hormone-producing cells		Cholesterol	Remove and degrade cholesterol

LDLs are Lousy; HDLs are Healthy

Large Intestine

- Final water absorption
- Compaction, storage, & excretion of feces
 - 1/3 bacteria by weight (some make K & B vitamins).
 - Brown color from bile pigments of RBC breakdown.

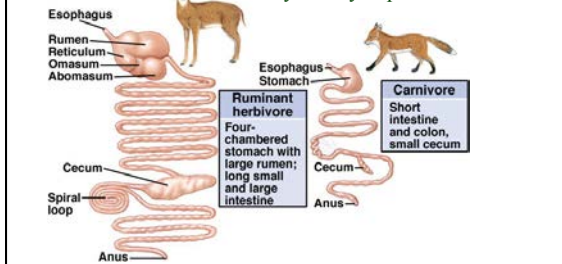


Digestion Overview

	(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 ↓ Nucleosides	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	

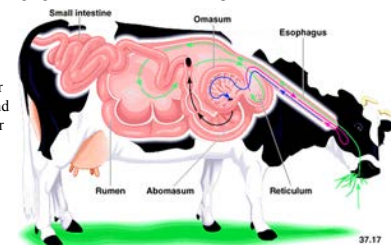
Carnivores Have Short Tracts Herbivores Have Long Tracts

- **Plant material much harder to digest.**
 - Aided by cellulytic protists & bacteria



Ruminant herbivores

- Masticated vegetation swallowed into **rumen**
 - First of four stomach chambers
- Cultures of microbes digest the cellulose and other complex carbohydrates
 - Occasionally regurgitate and rechew cud to aid process
- Microbial populations actual food
 - Pass to other chambers and intestines for digestion & absorption



Non-ruminant herbivores

- Cellulytic protists & bacteria in **cecum**
 - Enlarged region of large intestine right after junction with small intestine
- Plant carbs metabolized by microbes into free fatty acids (FFA)
- FFAs can be absorbed by large intestine

Ruminants re-chew a cud. Rabbits and other juvenile non-ruminants re-chew by **coprophagy**

Digestion in the Horse

Patricia Mills — Omslone University

Non-ruminant herbivores

- Similar solution in **herbivorous reptiles**
- Cellulytic protists & bacteria in **enlarged colon**
 - Stomach=30% of total gut; colon=60%
- Plant carbs metabolized by microbes into volatile free fatty acids (FFA)
 - FFAs can be absorbed by large intestine
- BUT**, cellulytic microbes require warm temperatures!
 - \therefore *ectothermic* herbivorous reptiles are limited to tropics & deserts

Green iguana Green sea turtle

Lengthening Intestine to Meet Metabolic Demands

- House wrens lengthen 22% in winter
- Mammals lactating
- All eat more too

WHAT HAPPENS TO IT ALL?

Feeding & Digestion

Fate of Chemical Energy

- Stored as
 - blood sugars
 - liver & muscle glycogen
 - body fat
- Stored energy used for
 - 1) metabolism
 - 2) growth
 - many insects don't feed as adults
 - 3) reproduction

