Animal Form & Function- II

Completer Handouts

Animal Form & Function – II, Course Code: 302

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Chapter#1

Nutrition and Digestion

Nutrition includes all of those processes by which an animal takes in, digests, absorbs, stores, and uses food (nutrients) to meet its metabolic needs.

In this chapter we shall discuss:

- Animal nutrition,
- Different strategies animals use for consuming and using food, and
- Various animal digestive systems.

Nutrients:

- A nutrient is a component in foods that an organism uses to survive and grow.
- Nutrients may be organic or Inorganic.
- Organic nutrients consist of carbohydrates, fats, proteins (or their building blocks, amino acids), and vitamins.
- Inorganic nutrients: These are dietary minerals, water and oxygen.

Digestion is the chemical and/or mechanical breakdown of complex food into diffusible molecules i.e. particles that individual cells of an animal can absorb.

- Starch into glucose.
- Proteins into amino acids.
- Fats into fatty acids & glycerol.

Evolution of Nutrition

- Green plants and photosynthetic protists have the fewest such nutritional requirements because they can synthesize all their own complex molecules from simpler inorganic substances; they are autotrophs.
- Animals, fungi, and bacteria that cannot synthesize many of their own organic molecules and must obtain them by consuming other organisms or their products are heterotrophs.
- Overall, the nutritional requirements of an animal are inversely related to its ability to synthesize molecules essential for life.
- The fewer such biosynthetic abilities an animal has, the more kinds of nutrients it must obtain from its environment.
- Animals such as rabbits that survive entirely on plant material are herbivores.
- Carnivores such as hawks are animals that eat only meat.
- Omnivores such as humans, bears, raccoons, and pigs, eat both plant and animal matter.
- Insectivores, such as bats, eat primarily arthropods.

Metabolic Rates of Nutrients in Heterotrophs

The nutrients that a heterotroph ingests can be divided into:

- Macronutrients and
- Micronutrients

Macronutrients

Carbohydrates
Fats
Proteins

- Monosaccharides e.g. *Glucose, Fructose, Galactose*
- Disaccharides e.g. *Sucrose, Lactose*
- Polysaccharides e.g. *Starches, Glycog*en

Fats:

- Fatty acids
- Oils

Micronutrients

Micronutrients are needed in small quantities and include:

- Organic vitamins and
- Inorganic minerals.

Besides these nutrients, animals require water.

Calories and Energy

- Calorie: The energy value of food is measured in terms of calories or Calories.
- A calorie is the amount of energy required to raise the temperature of 1 g of water to 1° C.
- A calorie, with a small c, is also called a gram calorie.
- A kilocalorie, also known as a Calorie or kilogram calorie (kcal), is equal to 1,000 calories.
- Calories in food provide energy in the form of heat so that our bodies can function.
- Our bodies' store and "burn" calories as fuel.
- Many dieters count calories and try to decrease caloric intake to lose weight.

AVERAGE CALORIC VALUES OF MACRONUTRIENTS

Macronutrients	calories per gram
Carbohydrates	4.1
Lipids	9.3
Proteins	4.3

One calorie contains 4.184 joule (SI unit of energy) International Steam Table

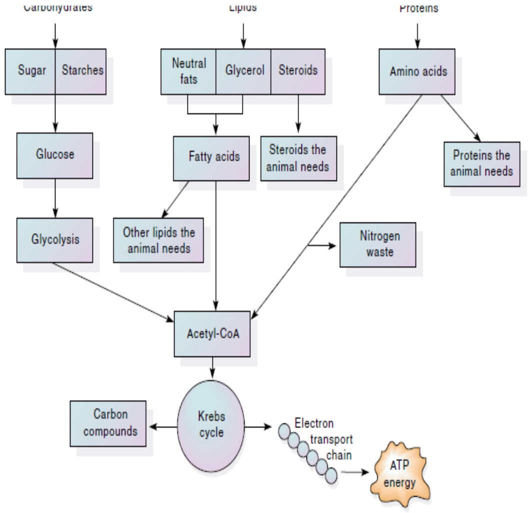
- *One joule of work is done on an object when a force of one newton is applied over a distance of one meter.*

Healthy foods that are high in calories include:

- One avocados (227 calories)
- 1 cup pea nuts (828 calories)
- 1 tablespoon of olive oil (119 calories)
- I cup of skimmed milk (86 calories).
- 1 cup low fat yogurt (225 cals)

Macronutrients (Carbohydrates)

- Complex carbohydrates are the major dietary source of energy for heterotrophs.
- Most carbohydrates originally come from plant sources.
- Various polysaccharides, disaccharides, or any of monosaccharides (simple sugars) can meet this dietary need.
- Carbohydrate foods break down to their constituent sugars and starches, and ultimately into glucose.
- Individual cells use this sugar in glycolysis and aerobic respiration to create new carbon compounds or ATP energy.



Macronutrients (Lipids)

- Lipids: Highly Compact Energy Storage Nutrients
- Neutral lipids (fats) or triacylglycerols are contained in fats and oils, meat and dairy products e.g. Nuts, Fruits and Vegetables.
- Lipids are the most concentrated source of food energy.
- They produce about 9 Calories (kcal) of usable energy per gram, more than twice the energy available from an equal mass of carbohydrate or protein.
- Many heterotrophs have an absolute dietary requirement for lipids, sometimes for specific types. For example, many animals require unsaturated fatty acids (e.g., linoleic acid, linolenic acid, and arachidonic acid.
  - Linolenic acid $C_{18}H_{30}O_2$
  - Linoleic acid $C_{18}H_{32}O_2$
  - Arachidonic $C_{20}H_{32}O_2$
- These fatty acids act as precursor molecules for the synthesis of sterols, the most common of which is cholesterol.
- The sterols are also required for the synthesis of steroid hormones and cholesterol, which is incorporated into cell membranes.
- Other lipids insulate the bodies of some vertebrates and help maintain a constant temperature.

Macromolecules (Proteins)

- Proteins: Basic to the Structure and Function of Cells.
- Animal sources of protein include other animals and milk.
- Plant sources include beans, peas, and nuts.
- Proteins are needed for their amino acids, which heterotrophs use to build their own body proteins.

An overview of Protein Functions

- **Structural proteins**
  Support e.g. Collagen, Keratin
- **Storage Proteins**
  Storage of amino acids e.g. Albumin, Casein
- **Transport proteins**
  Transport of other proteins e.g. Hemoglobin
- **Hormonal proteins**
  Coordination of activities e.g. Insulin
- **Contractile Proteins**
  Movement e.g. Actin and myosin
- **Defensive proteins**
  Protection against disease e.g. Antibodies
- **Enzymatic**
  Acceleration of chemical reactions. e.g. Pepsin, trypsin.

Micronutrients

Micronutrients are usually:

i) Inorganic minerals.
ii) Vitamins,

- They are needed in small amounts i.e. in milligrams.
- Animals cannot synthesize them rapidly, thus, they must be obtained from the diet.

Inorganic Minerals:

- i) Macrominerals
- ii) Micromineals

Minerals needed in relatively large amounts as compared to microminerals are called macrominerals or essential minerals.

Macrominerals:

- Examples are:

Calcium, Chlorine, Magnesium, Potassium, Phosphorus, Sodium, Sulfur etc.

Calcium

- Most adults need about 1,000 milligrams of calcium per day.
- Ca is the chief component of bone and teeth; essential for normal blood clotting; needed for normal muscle, neuron, and cellular functioning.

Chlorine:

- Cl is the principal negative ion in extracellular fluid; important in acid-base and fluid balance; needed to produce stomach HCl.

Magnesium

- Mg is the component of many coenzymes; needed for normal neuron and muscle function. as well as carbohydrate and protein metabolism .

Potassium (K)

- Major constituent of bones, blood plasma; needed for energy metabolism.

Phosphorus (P)

- Major positive ion in cells; influences muscle contraction and neuron excitability; part of DNA, RNA, ATP, energy metabolism.

Sodium (Na)

- Principal positive ion in extracellular fluid; important in fluid balance; essential for conduction of action potentials, active transport.

Sulfur (S)

- Protein structure; detoxification reactions and other metabolic activity.
- Animals excrete large quantities of these minerals, especially sodium, in the urine every day.
- Animals that sweat to help regulate body temperature lose sodium in their sweat.

PHYSIOLOGICAL ROLES OF THE ESSENTIAL MINERALS (MACROMINERALS) ANIMALS REQUIRE IN LARGE AMOUNTS

MINERAL	MAJOR PHYSIOLOGICAL ROLES
Calcium (Ca)	Component of bone and teeth; essential for normal blood clotting; needed for normal muscle, neuron, and cellular function
Chlorine (Cl)	Principal negative ion in extracellular fluid; important in acid-base and fluid balance; needed to produce stomach HCl
Magnesium (Mg)	Component of many coenzymes; needed for normal neuron and muscle function, as well as carbohydrate and protein metabolism
Potassium (K)	Major constituent of bones, blood plasma; needed for energy metabolism
Phosphorus (P)	Major positive ion in cells; influences muscle contraction and neuron excitability; part of DNA, RNA, ATP, energy metabolism
Sodium (Na)	Principal positive ion in extracellular fluid; important in fluid balance; essential for conduction of action potentials, active transport
Sulfur (S)	Protein structure; detoxification reactions and other metabolic activity

Micronutrients

- i) Inorganic minerals.
- ii) Vitamins,

Micronutrients

- needed in small amounts i.e. in micro milligrams also called trace minerals.
- Like macronutrients animals cannot synthesize them thus, they also must be obtained from the diet.

Micronutrients:

Copper, Fluorine, Cobalt, Iodine, Iron, Manganese, Molybdinum , Selenium, Zinc

Examples of Trace Minerals:

Copper (Cu)

- Component of many enzymes; essential for melanin and hemoglobin synthesis; part of cytochromes.

Fluorine (F)

- Component of bone and teeth; prevents tooth decay.

Cobalt (Co)

- Component of vitamin B12; essential for red blood cell production.

Iodine (I)

- Component of thyroid hormones

Iron (Fe)

- Component of hemoglobin, myoglobin, enzymes, and cytochromes.

Manganese (Mn)

- Activates many enzymes; an enzyme essential for urea formation and parts of the Krebs cycle

Molybdenum (Mo)

- Constituent of some enzymes.

Selenium (Se)

- Needed in fat metabolism

Zinc (Zn)

- Component of at least 70 enzymes.
- Needed for wound healing and fertilization.

Vitamins

Vitamins are the organic substances that occur in many foods in small amounts and are necessary for normal metabolic functioning.

Vitamins may be:

i) Water soluble
ii) Fat soluble.

Most water-soluble vitamins are B vitamins and vitamin C.
Fat soluble vitamins include vitamins A, D, E and K.

Water Soluble B-Vitamins

- Vitamin B1 (thiamine)
- Vitamin B2 (riboflavin)
- Vitamin B3 (niacin)
- Vitamin B5 (pantothenic acid)
- Vitamin B6 (pyridoxine
- Vitamin B7 (biotin)
- Vitamin B9 (folic acid)
- Vitamin B12 (cobalamin)

VITAMIN A

Characteristics:

- Occurs in several forms; synthesized from carotenes.
- Stored in liver.
- Stable in heat, acids, and alkalis;
- Unstable in light.

Functions:

- Necessary for synthesis of visual pigments, mucoproteins, and mucopolysaccharides
- Necessary for normal development of bones and teeth.
- Necessary for the maintenance of epithelial cells.

Source

- Liver, fish, whole milk, butter, eggs, leafy, green vegetables, and yellow and orange vegetables and fruits.

VITAMIN D

Characteristics:

- A group of sterols;
- Resistant to heat, oxidation, acids and alkalis.
- Stored in liver, skin, brain, spleen and bone.

Functions:

- Promotes absorption of Ca and P.
- Promotes development of teeth and bones.

Sources

- Produced in skin exposed to ultraviolet light.
- Milk, fish-liver oils, egg yolk, fortified foods (enriched food)

VITAMIN E

Characteristics

- A group of compounds; resistant to heat and visible light;
- Unstable in presence of oxygen and UV light
- Stored in muscles and adipose tissue.

Functions

- An antioxidant;
- Prevents oxidation of itamin A and PUFAs.*(Poly Unsaturated Fatty Acids)*
- May help maintain stability of cell membranes.

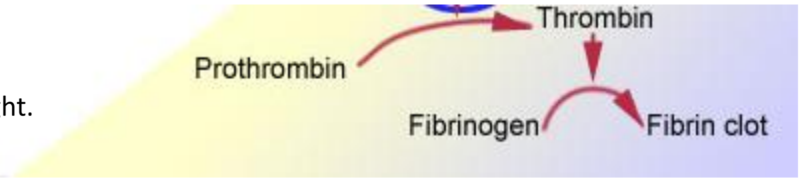
Sources:

- Oils from cereal seeds, salad oils, margarine, shortenings, fruits, nuts, and vegetables.

Vitamin K

Characteristics

- Occurs in several forms;
- Resistant to heat,
- Destroys by acids, alkalis and light.
- Stored in liver.



Functions

- Needed for the synthesis of prothrombin.
- Needed for blood clotting
- Prothrombin, or factor II, is one of the clotting factors made by the liver.
- Vitamin K is needed to make prothrombin and other clotting factors

Water Soluble Vitamins

VITAMIN B1 (THIAMIN)

Characteristics:

- Destroyed by heat and oxygen especially in alkaline environment

Functions:

- Part of coenzyme needed for oxidation of carbohydrates and in synthesis of ribose.

Sources:

- Lean meats, liver, eggs, whole grain cereals, leafy green, vegetables, and legumes.

VITAMIN B2 (RIBOFLAVIN)

Characteristics:

- Stable to heat, acids, and oxidation; destroyed by alkalis and light.

Functions:

- Part of enzymes and coenzymes.
- Needed for oxidation of glucose and fatty acids and for cellular growth.

Sources:

- Meats, dairy products, leafy green vegetables, whole grain cereals.

VITAMIN B3 (NIACIN)

Characteristics:

- Stable to heat, acids, and alkalis;
- Converted to niacinamide by cells;
- Synthesized from tryptophan.

Functions:

- Part of coenzymes needed for oxidation of glucose and synthesis of
- Proteins, fats, and nucleic acids.

Sources:

- Liver, lean meats, poultry, peanuts, legumes.

VITAMIN B5 (PANTOTHENIC ACID)

Characteristics:

- Destroyed by heat, acids, and alkalis.

Functions:

- Part of coenzyme needed for oxidation of carbohydrates and fats.

Sources:

- Meats, fish, whole-grain cereals, legumes, milk, fruits, vegetables.

VITAMIN B7 (BIOTIN)

Characteristics:

- Stable to heat, acids, and light destroyed by oxidation and alkalis.

Functions:

- Coenzyme needed for metabolism of amino acids and fatty acids.
- Also important for the synthesis of nucleic acid.

Sources:

- Liver, egg yolk, nuts, legumes, mushrooms.
- Deficiency:
- No appetite, anemia, scaly skin, weight loss, hair loss.

VITAMIN B9 (FOLIC ACID)

Characteristics:

- Destroyed by oxidation in acid or by heat in alkaline environment.
- Stored in liver.

Resource:

- Liver, leafy green vegetables, whole-grain cereals, legume.

Functions:

- Coenzyme needed for metabolism of certain amino acids and for the synthesis of DNA
- Promotes production of normal RBCs.

Deficiency:

- Anemia, diarrhea, miscarriage, birth defects.

VITAMIN B12 (CYANOCOBALAMINE)

Characteristics:

- Complex, cobalt-containing compound.
- Stable to heat.
- Inactivated by light, strong acids and strong alkalis.
- Absorption regulated by intrinsic factor from gastric glands.
- Stored in liver.

Functions

- Part of coenzyme needed for the synthesis of Nucleic acids and for the metabolism of carbohydrates.
- Plays role in synthesis of myelin.

Source

- Liver, meats, poultry, fish, milk, cheese, eggs.

Deficiency:

- Anemia, degenerative changes in NS.

DIGESTION AND ITS TYPES

Digestion:

The breakdown of complex organic compounds of food into simpler diffusible molecules by the action of enzymes. i.e.

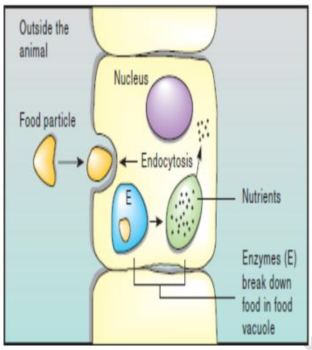
- Proteins into amino acids.
- Carbohydrates into simple sugars.
- Fats into fatty acids and glycerol.

Digestion is of two main types:

Intracellular and
Extracellular

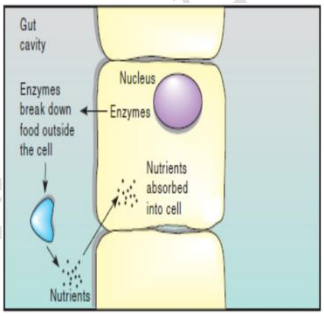
In intracellular digestion breakdown of food occurs within the cells.

- First food in taken into the cell vacuole.
- The cytoplasm secretes digestive enzymes into the food vacuole.
- Enzymes break larger molecules into smaller ones, which enter the cytoplasm.



- In extra cellular digestion, the enzymes are secreted outside the cell into the gut cavity or lumen where digestion occurs.

- Nutrients from the food then pass into body cells for energy metabolism or biosynthesis.



Animal Strategies for Getting and Using Food

Mostly protists and a few animals can absorb nutrients directly from their external environment (i.e. intracellular digestion).
Most animals work for their nutrients.
Following are the specializations that have evolved for feeding and extracellular digestion.

Various Specializations for Getting Food:

1. Continuous feeders
2. Discontinuous feeders
3. Suspension feeders
4. Deposit feeders
5. Herbivory
6. Predation
7. Surface Nutrient Absorption
8. Fluid feeders

1. Continuous Feeders

- Continuous feeders are slow-moving or completely sessile animals.
- For example,
- Tube worms and barnacles, that remain in one place and continuously “strain” small food particles from the water.

2. Discontinuous feeders:

i) Carnivores
ii) Herbivores

i) Carnivores:

- They tend to be active, sometimes highly mobile, animals.
- Typically, discontinuous feeders have more specialized digestive systems than continuous feeders.
- This is because discontinuous feeders take in large meals.
- For example, Lion, Tigers, cat, dogs
- They capture relatively large prey.
- Spend their time in the continuous pursuit of prey.
- Thus, carnivores have digestive systems that permit the storage and gradual digestion of large, relatively infrequent meals.

ii) Herbivores:

- They spend more time eating than carnivores do.
- They need to move from area to area.
- When food is exhausted in natural environments, they limit their grazing time to avoid excessive exposure to predators.
- Thus, their digestive systems permit relatively rapid food gathering and gradual digestion.

3. **Suspension feeder:**

- An animal that feeds on material (such as planktonic organisms) suspended in water and that usually has various structural modifications for straining out its food.
- Suspension feeding is the capture and ingestion of food particles that are suspended in water.
- These particles can include phytoplankton, zooplankton, bacteria.
- Suspension feeding is the removal of suspended food particles from the surrounding water by some sort of capture, trapping, or filtration structure.

This feeding strategy involves three steps:

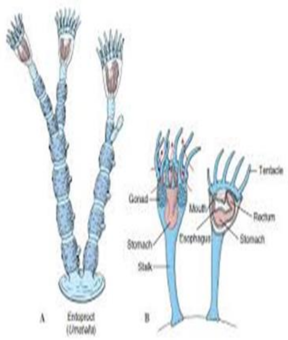
(1) Transport of water past the
- feeding structure.

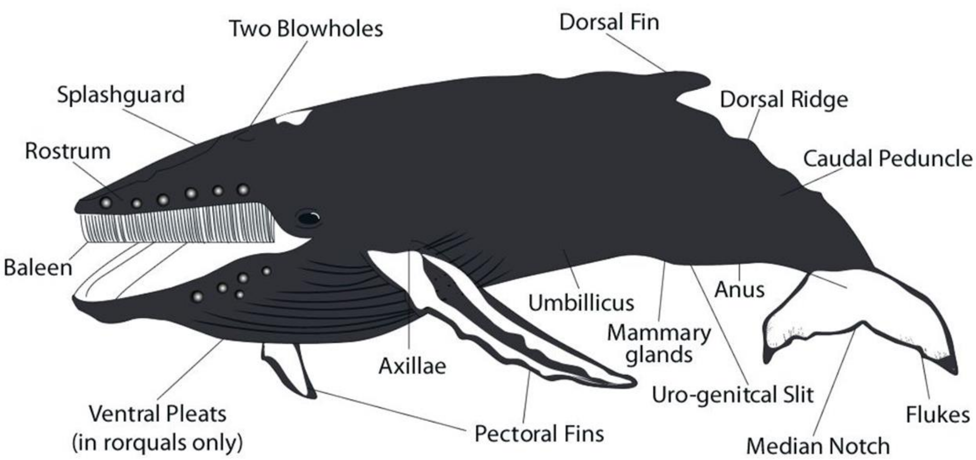
(2) Removal of nutrients from
- the water,

(3) Transport of the nutrients to
- the mouth of the Digestive
- System

Sponges

Brachiopods





4. Deposit Feeders

- Deposit feeders are the animals which are primarily the omnivorous.
- These animals obtain their nutrients from muds and sands or terrestrial soils.
- Deposit feeders simply swallow large quantities of sediment (mud, soil, sand, organic matter).
- The usable nutrients are digested, and the remains pass out the anus.
- Deposit feeding occurs in:
  - Many polychaete
  - Annelids,
  - Some snails,
  - Some sea urchins and
  - Most earthworms.
- Other Examples are sea cucumber that utilize tentacle like structures to consume sediment.
- Most sipunculans, certain clams, and several types of polychaetes are more examples of deposit feeders.

Sea cucumber

Sea Urchin

Sipunculans

Clams

Polychaetes

Earthworm

5. Herbivory

Herbivory is the consumption of macroscopic plants.

- This common feeding strategy requires the ability to "bite and chew'' large pieces of plant matter (macroherbivory).
- Invertebrates that evolved macroherbivory include molluscs, polychaete worms, arthropods, and sea urchins.
- Macroherbivory is found in almost every group of arthropods.
- For example, insects and crustaceans have large, powerful mandibles capable of biting off plant material and subsequently grinding and chewing it before passing the plant material to the mouth
- Many molluscs have a radula.
- A radula is a muscularized, belt-like rasp armed with chitinous teeth.
- Molluscs use the radula to scrape algae off rocks or to tear the leaves off terrestrial plants.
- Polychaetes have sets of large chitinous teeth on an eversible proboscis or pharynx that is used to scrape off algae.
- This toothed pharynx is also suitable for carnivory when plant material is scarce.
- Macroherbivory is found in almost every group of Arthropods.
- For example, insects and crustaceans have large, powerful mandibles capable of biting off plant material and subsequently grinding and chewing it before passing the plant material to the mouth.

6. Predation

- Predation: is one of the most sophisticated feeding strategies, since it requires the capture of live prey.
- Only a few generalizations about the many kinds of predation are presented here.
- Predators can be classified by how they capture their prey:
  - Motile stalkers,
  - Lurking predators,
  - Sessile opportunists and
  - Grazers.
- Motile stalkers actively pursue their prey.
- Examples include ciliates nemerteans, polychaetes gastropods, octopuses and squids, crabs, sea stars, and many vertebrates.

- **Lurking predators** sit and wait for their prey to come within seizing distance. Examples include certain species of praying mantises, shrimp, crabs, spiders, polychaetes, and many vertebrates.
- **Sessile opportunists** usually are not very mobile. They can only capture prey when the prey organism comes into contact with them.
- Examples include certain protozoa, barnacles, and cnidarians.
- Grazing carnivores move about the substrate picking up small organisms.
- Their diet usually consists largely of sessile and slow-moving animals, such as sponges, ectoprocts, tunicates, snails, worms, and small crustaceans.

Stalker predator

Ectoprocts and Bryozoans

7. **Surface Nutrient Absorption**

Some highly specialized animals have dispensed entirely with all mechanisms for prey capture, ingestion of food particles, and digestive processes.

Instead they directly absorb nutrients from the external medium across their body surfaces.

This medium may be:

- Nutrient-rich seawater
- Fluid in other animals' digestive tracts,
- Body fluids of other animals.

Examples:

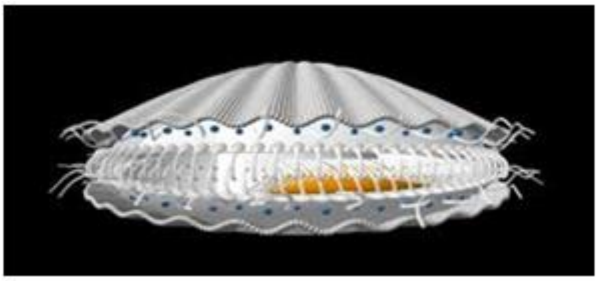
Some free-living protozoa, such as Chilomonas, absorb all of their nutrients across their body surface.

Endoparasites:

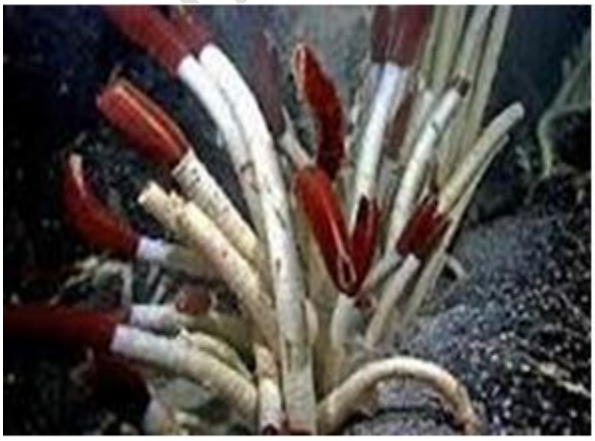
a) Protozoa
b) cestode worms
c) Gastropods
d) Crustaceans

All these parasites lack mouths and digestive systems.

- A few non-parasitic multicellular animals also lack a mouth and digestive system and absorb nutrients across their body surface.
- Examples include the gutless bivalves and pogonophoran worms.
- Interestingly, many pogonophoran worms absorb some nutrients from seawater across their body surface.
- They also supplement their nutrition with organic carbon that symbiotic bacteria fix within the pogonophoran's tissues (Tube dwelling marine animals)



Prognophorans



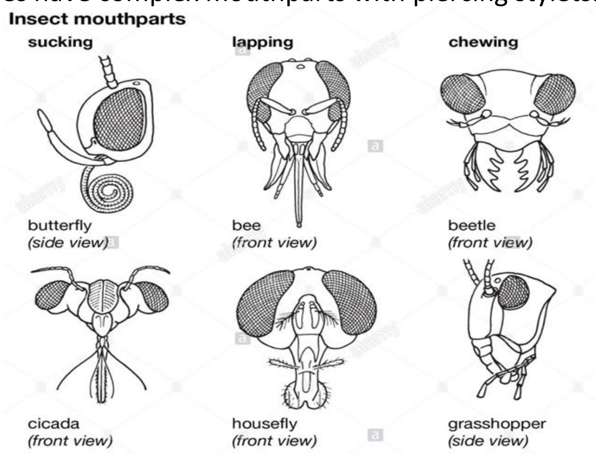
8. **Fluid Feeders**

- Fluid Feeders are the animals which feed on biological fluids of animals and plants.
- These fluids are a rich source of nutrients.
- Fluid feeding is the characteristic of some parasites, such as the intestinal nematodes that bite and rasp off host tissue or suck blood.
- External parasites (ectoparasites), such as leeches, ticks, mites, lampreys, and certain crustaceans, use a wide variety of mouthparts to feed on body fluids.
- For example, the sea lamprey has a funnel structure surrounding its mouth.
- The funnel is lined with over 200 rasping teeth and a rasp like tongue.
- The lamprey uses the funnel like a suction cup to grip its fish host, and then with its tongue, rasps a hole in the fish's body wall.
- The lamprey then sucks blood and body fluids from the wound.

Aphids

• Lampray

- Insects have the most highly developed sucking structures for fluid feeding.
- For example, butterflies, moths, and aphids have tube-like mouthparts that enable them to suck up plant fluids.
- Blood-sucking mosquitoes have complex mouthparts with piercing stylets.



- Some nectar-feeding birds have long bills and tongues.
- In fact, the bill is often specialized for particular types of flowers.
- Other nectar-feeding birds have short bills; they make a hole in the base of a flower and use their tongue to obtain nectar through the hole.

Humming bird

- The only mammals that feed exclusively on blood are the vampire bats.
- Such as *Desmodus*, of tropical South and Central America.
- These bats attack birds, cattle, and horses, using knife sharp front teeth to pierce the surface blood vessels, and then lap at the oozing wound.

Desmodus

- Nectar-feeding bats have a long tongue to extract the nectar from flowering plants
- The nectar-feeding honey possum has a long, brush-tipped tongue and reduced dentition.

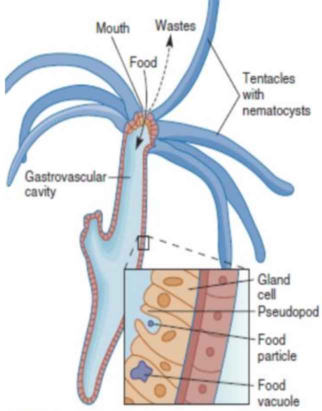
Nectar- feeding bat

- The nectar-feeding honey possum has a long, brush-tipped tongue and reduced dentition.

Honey Possum

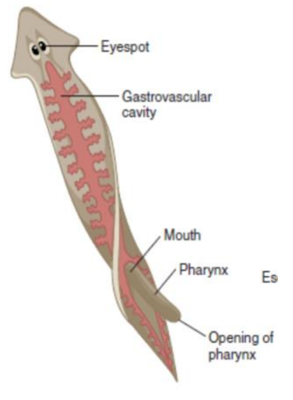
Diversity in Digestive Structures in Invertebrates

- In primitive, multicellular animals, such as cnidarians, the gut is a blind (closed) sac called a gastrovascular cavity.
- It has only one opening that is both entrance and exit thus, it is an incomplete digestive tract.
- Some specialized cells in the cavity secrete digestive enzymes that begin the process of extracellular digestion.
- Other phagocytic cells that line the cavity engulf food material and continue intracellular digestion inside food vacuoles.



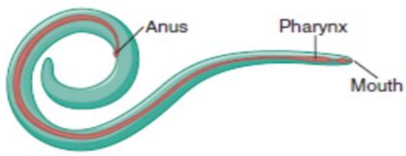
a) Cnidarian (*Hydra*)

- In Platyhelminth (planarian) Gastric cavity branches extensively having Single opening.
- When a planarian feeds, it sticks its muscular pharynx out of its mouth and sucks in food.



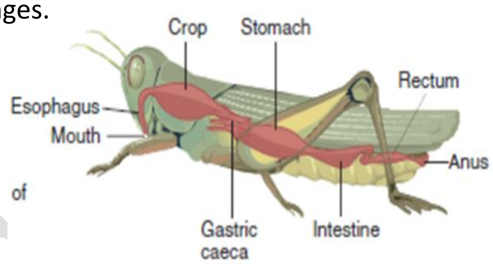
(b) Planarian

- In Aschelminths the digestive tract is complete, that permits the one-way flow of ingested food without mixing it with previously ingested food or waste.
- A nematode (Ascaris) has a complete digestive tract with a mouth, pharynx, and anus.



(c) Nematode

- In insects (grasshopper) the complete digestive tract has an expanded region called a crop that functions as a food storage organ.
- These are evolutionary changes.



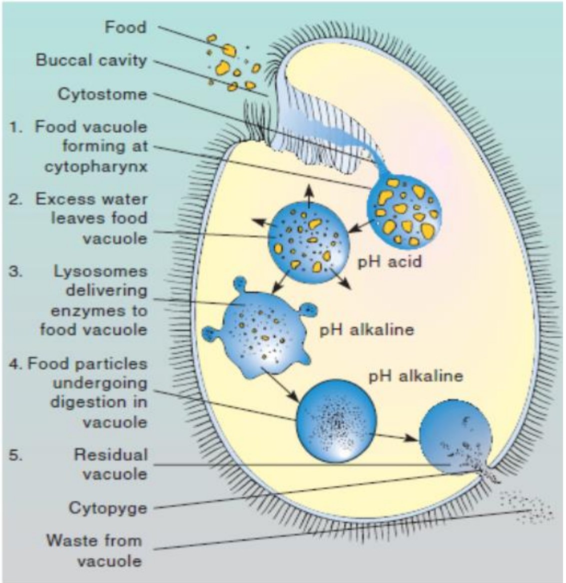
(d) Insect

Digestion in Protozoa

- Ciliated protozoa are good examples of protists that utilize heterotrophic nutrition.
- Ciliary action directs food from the environment into the buccal cavity and cytostome.
- The residual vacuole then excretes its waste products via the cytopyge.
- The cytostome opens into the cytopharynx, which enlarges as food enters and pinches off a food-containing vacuole.
- The detached food vacuole then moves through the cytoplasm.
- During this movement, excess water is removed from the vacuole, the contents are acidified and then made alkaline and a lysosome adds digestive enzymes.
- The food particles are then digested within the vacuole and the nutrients absorbed into the cytoplasm.

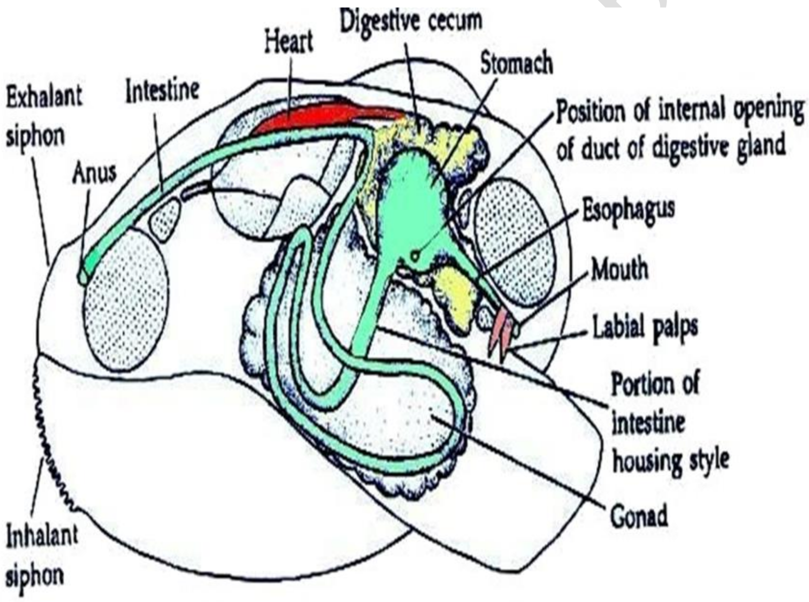
Intracellular Digestion in a Ciliated Protozoan.

- Cilia direct food toward the cytostome (“mouth’’).
- The food enters the cytopharynx, where a food vacuole forms and detaches from the cytopharynx.
- The detached vacuole undergoes acidic and alkaline digestion, and the waste vacuole moves to the cytopyge (“anus’’) for excretion.



Digestion in Mollusca

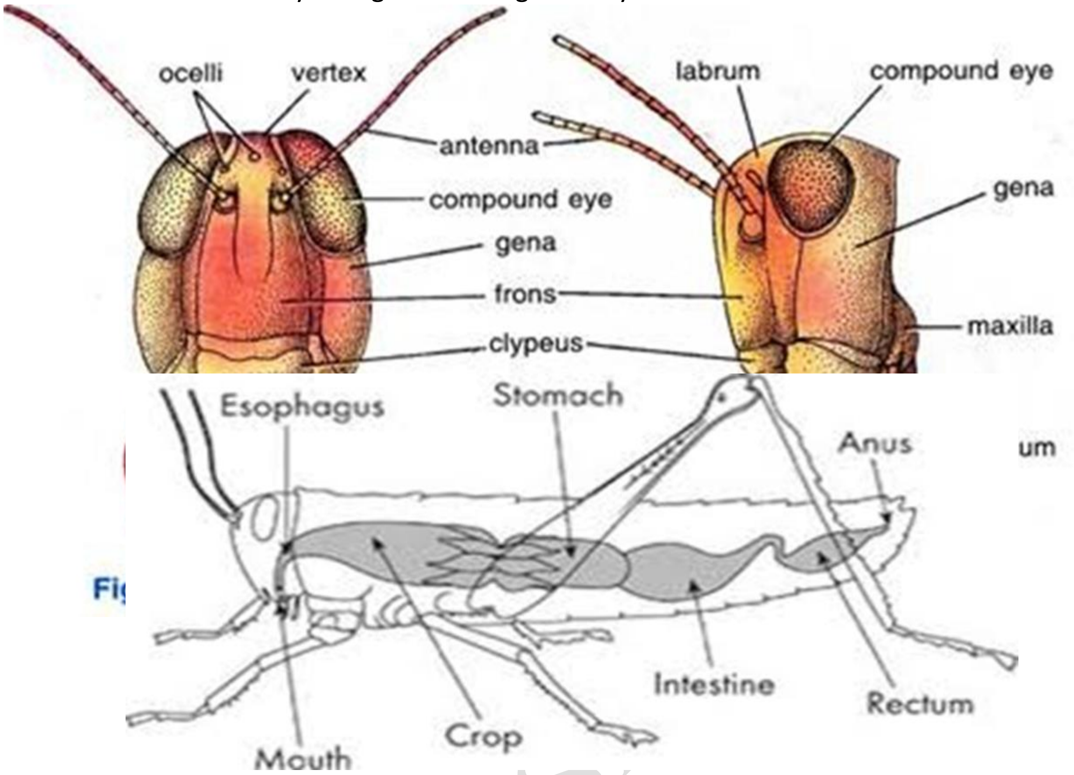
- Many bivalves feed or ingest suspended small food particles.
- The digestive tract has a short esophagus opening into a stomach, midgut, hindgut, and rectum.
- The stomach contains a crystalline style, gastric shield, and diverticulated region.



- These diverticulae are blind-ending sacs that increase the surface area for absorption and intracellular digestion.
- The midgut, hindgut, and rectum function in extracellular digestion and absorption
- Digestion is a coordination of three main steps:
  (1) feeding,
  (2) extracellular digestion,
  (3) intracellular digestion.
- The resting phase is preparative for extracellular digestion.
  (a) Extracellular digestion begins before food ingestion fragmentation spherules in the stomach.
  (b) As food enters the stomach, the rotating style and the enzymes released by the gastric shield mechanically and enzymatically break it down.
  (c) The small food particles then move into the digestive diverticulae for intracellular digestion.
  (d) A progressive passage of food particles from the stomach to the digestive diverticulae follows cessation of feeding.
  e) During this resting phase, the stomach empties and the style reforms, while intracellular digestion in the diverticulae is completed, and fragmentation spherules begin to form again. The movement of fragmentation spherules starts the next feeding cycle.

Digestion in Insects

- The grasshopper is a representative insect with a complete digestive tract.
- During feeding, the mandibles and maxillae first break up (masticate) the food, which is then taken into mouth and passed to the crop via the esophagus.
- During mastication, the salivary glands add saliva to the food to lubricate it for passage through the digestive tract.
- These are the evolutionary changes in the digestive system.



- Saliva also contains the enzyme amylase, which begins the enzymatic digestion of carbohydrates.
- This digestion continues during food storage in the crop.
- The midgut secretes other enzymes (carbohydrases, lipases, proteases) that enter the crop.
- Food passes slowly from the crop to the stomach, where it is mechanically reduced and the nutrient particles sorted.
- The glands in the walls of stomach and hepatic caeca secrete a few enzymes which bring about digestion.
- The slightly alkaline or acidic secretions of midgut contain maltase, lipase, lactase, protease, trypsin and erepsin.
- The absorption of food material takes place in the midgut.
- Most nutrient absorption then occurs in the intestine.
- Undigested food is moved along the intestine and passes into the rectum, where water and ions are absorbed.
- The solid fecal pellets that form then pass out of the animal via the anus.
- During this entire feeding process the nervous system, the endocrine system, and the presence of food exert considerable control over enzyme production at various points in the digestive tract.

Diversity in Digestive Structures (Vertebrates)

- The complete vertebrate digestive tract (gut tube) is highly specialized in both structure and function for the digestion of a wide variety of foods.
- The basic structures of the gut tube include:
    - Buccal cavity
    - Pharynx,
    - Esophagus
    - Stomach
    - Small intestine
    - Large intestine
    - Rectum, and Anus/Cloaca
- In addition, three important glandular systems associated with the digestive tract are:

  i) The salivary glands.
  ii) The liver, gallbladder, bile duct.
  iii) The pancreas and pancreatic duct.

- Most vertebrates spend the majority of their time acquiring food.
- The oral cavity (mouth), teeth, intestines, and other major digestive structures usually reflect the way an animal gathers food, the type of food it eats, and the way it digests that food.
- These major digestive structures are now discussed to illustrate the diversity of form and function among different vertebrates.

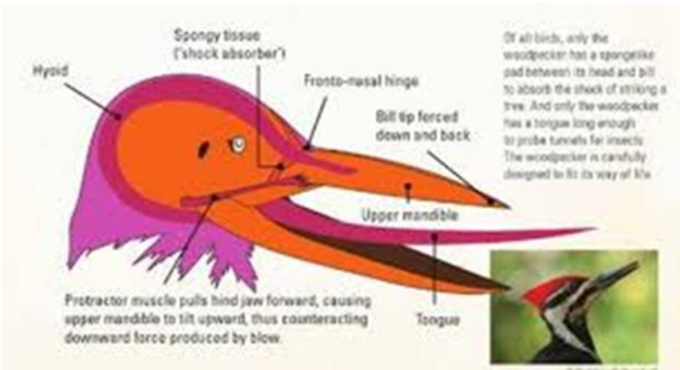
Tongues in Vertebrates

- Tongue or tongue-like structure develops in the floor of the oral cavity in many vertebrates.
- For example, a lamprey has a protrusible tongue with horny teeth that rasp its prey's flesh.
- The tongue of a fish is formed from a fold in the floor of the mouth. In some species of bony fishes the tongue has teeth which help to hold prey items.
- However, this type of tongue is not muscular.
- Tetrapods have evolved mobile tongues for gathering food.
- Frogs, salamanders and some lizards can rapidly project part of their tongue from the mouth to capture an insect.

Frog

Lizard

- A woodpecker has a long, spiny tongue for gathering insects and grubs ants.



- Spiny papillae on the tongues of cats and other carnivores help these animals rasp flesh from a bone.
- Pangolins have long, sticky tongues, which are often longer than their body.
- They need to have long to reach far inside ant nests.

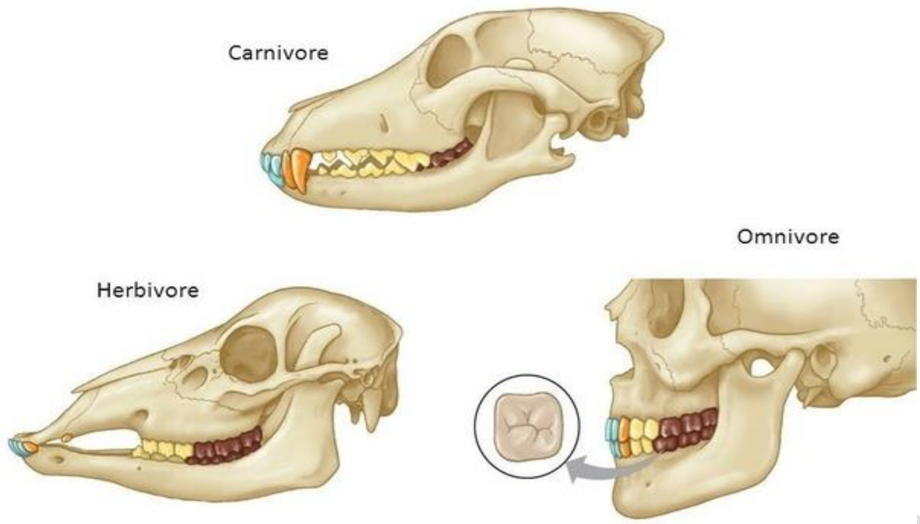
Teeth in Vertebrates

- Almost all vertebrates have teeth except birds, turtles, and baleen whales.
- Birds lack teeth, probably to reduce body weight for flight.
- The teeth of snakes slope backward to aid in the retention of prey while swallowing and the canine teeth of wolves are specialized for ripping food.

- Teeth are specialized, depending on whether an animal feeds on plants or animals, and on how it obtains its food

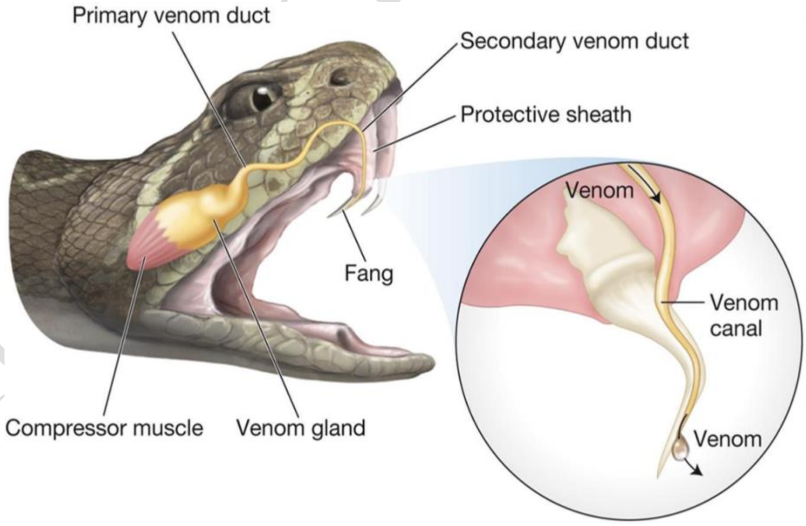
- Herbivores, such as deer, have predominantly grinding teeth.
- The front teeth of a beaver are used for chiseling trees and branches.
- The elephant has two of its upper, front teeth specialized as weapons and for moving objects.

- Because humans, pigs, bears, raccoons, and a few other mammals are omnivores, they have teeth that can perform a number of tasks—cutting grinding or mastication and tearing.

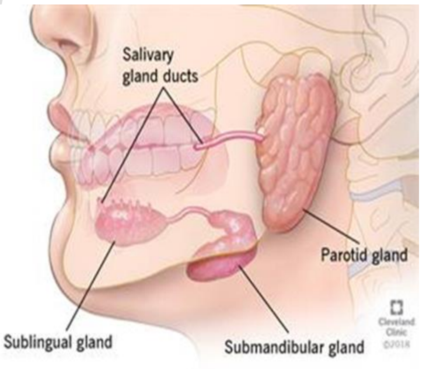


Salivary Glands in Vertebrates

- Most fishes lack salivary glands in the head region.
- Lampreys are an exception because they have a pair of glands that secrete an anticoagulant needed to keep their prey's blood flowing as they feed.
- Modified salivary glands of some snakes produce venom that is injected through fangs to immobilize prey.
- Because the secretion of oral digestive enzymes is not an important function in amphibians or reptiles, salivary glands are absent.



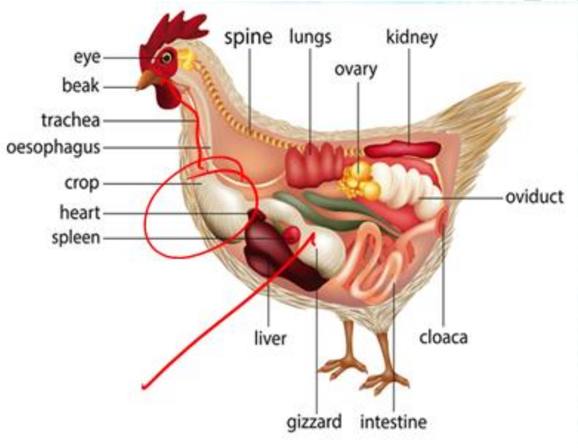
- Most birds lack salivary glands, while all mammals have them.



Esophagi in Vertebrates

- The esophagus is a muscular tube that connects the throat (pharynx) with the stomach.
- The esophagus is lined by moist tissue called mucosa. Esophagus runs behind the windpipe (trachea).
- In fishes and amphibians, the Esophagus is short.
- In amniotes the esophagus in much longer due to their longer necks.
- In birds particularly grain and seed-eaters, the esophagi have a crop that develops from the caudal portion of the esophagus.
- A bird's crop is an expandable “muscular pouch near the gullet or throat.” It is used to store excess food for later digestion.
- Storing food in the crop ensures an almost continuous supply of food to the stomach and intestine for digestion.
- This structure allows these birds to reduce the frequency of feeding and still maintain a high metabolic rate.
- Birds that have more visible crops include vultures, hawks, falcons, eagles, gulls, and many types of quail.

Crop in Vultures



Esophagus and Crop in Hen

Stomach in Vertebrates

Stomach

- The stomach is a muscular organ located on the left side of the upper abdomen.
- The stomach receives food from the esophagus.
- The stomach secretes acid and enzymes that digest food.

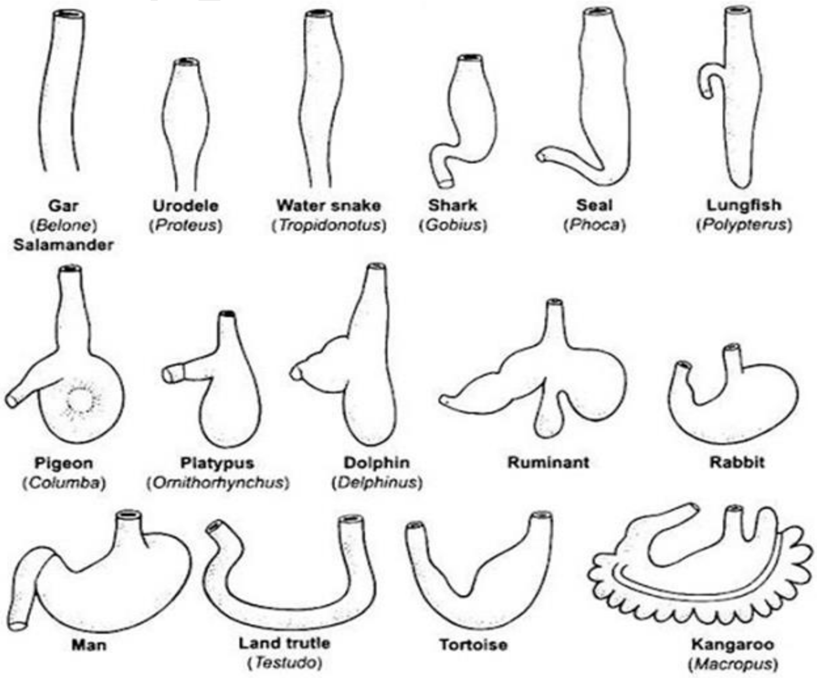


Fig. 43.10. Different shapes of vertebrate stomachs including human.

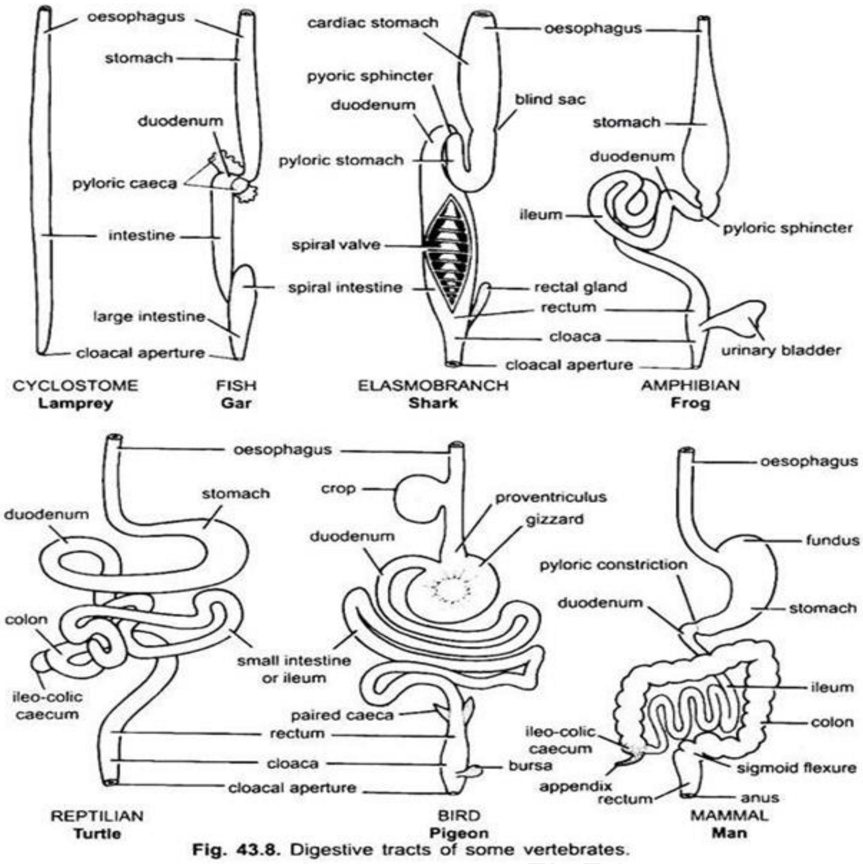


Fig. 43.8. Digestive tracts of some vertebrates.

Functions of Stomach:

- Temporary storage for food, which passes from the esophagus to the stomach where it is held for 2 hours or longer.
- Mixing and breakdown of food by contraction and relaxation of the muscle layers in the stomach.
- Digestion of food.

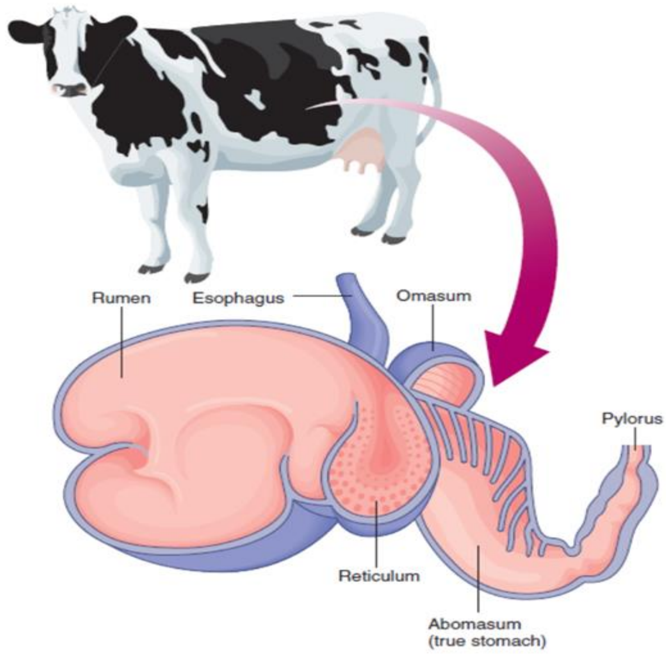
Gizzard in Vertebrates

Gizzard

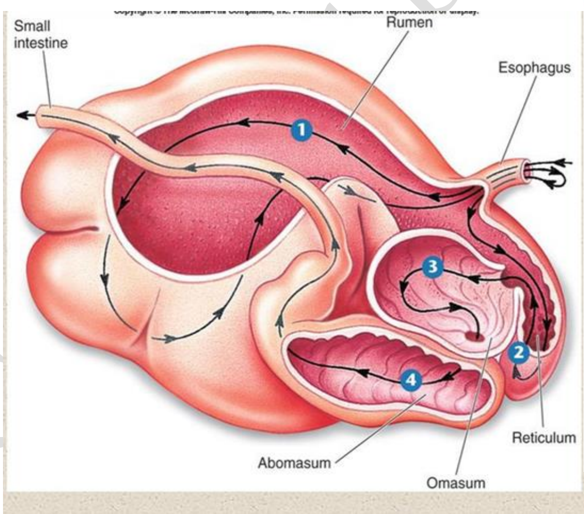
- The gizzard, is an organ found in the digestive tract of some animals.
- Gizzard is also referred to as the ventriculus, gastric mill, and gigerium.
- Gizzard has a thick muscular wall .
- Some fishes, some reptiles such as crocodile, and all birds have a gizzard for grinding up food.
- The bird's gizzard develops from the posterior part of the stomach called the ventriculus.
- Grain-eating birds swallow pebbles (grit) which are often retained in the gizzard to facilitate the grinding process grains.

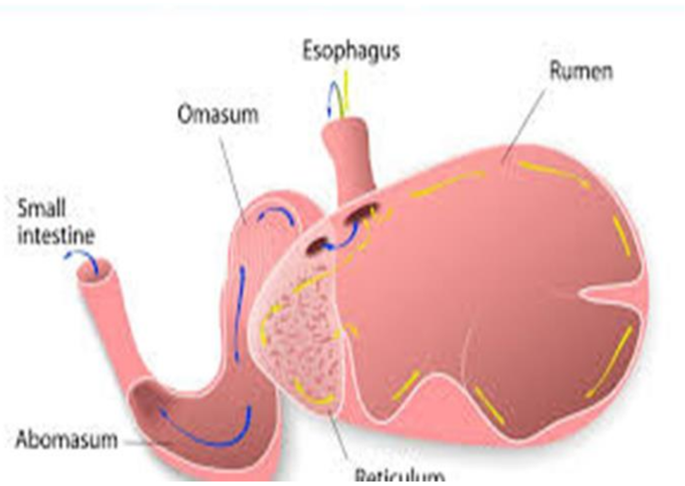
Stomach in Ruminants

- Ruminant mammals are the animals that “chew their cud,’’ such as cows, sheep, and deer—show some of the most unusual modifications of the stomach.
- This method of digestion has evolved in animals that need to eat large amounts of food relatively quickly, but can chew the food at a more comfortable or safer location.
- The ruminant stomach provides an opportunity for large numbers of microorganisms to digest the cellulose walls of grass and other vegetation.
- Cellulose contains a large amount of energy; however, animals generally lack the ability to produce the enzyme cellulase for digesting cellulose and obtaining its energy.
- Because gut microorganisms can produce cellulase, they have made the herbivorous lifestyle more effective.



- In ruminants, the upper portion of the stomach expands to form a large pouch, the rumen, and a smaller reticulum.
- The lower portion of the stomach consists of a small antechamber, the omasum, with a “true’’ stomach, or abomasum, behind it.

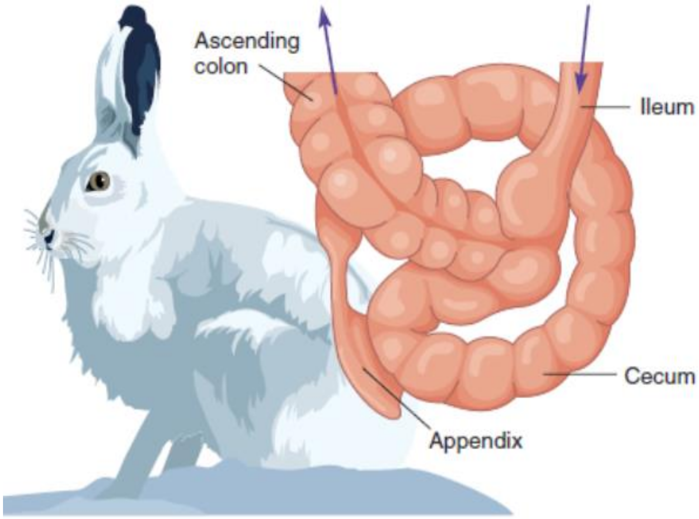


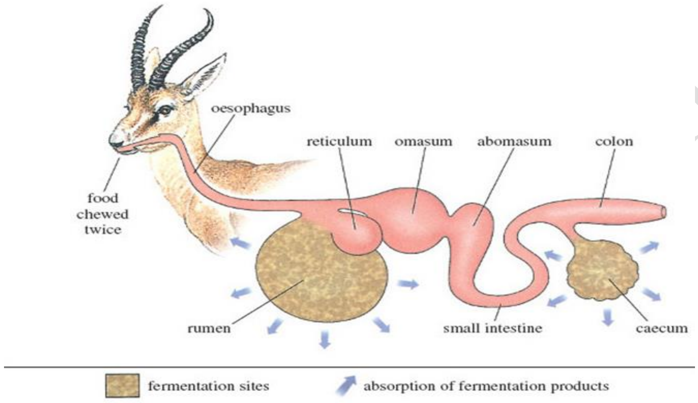


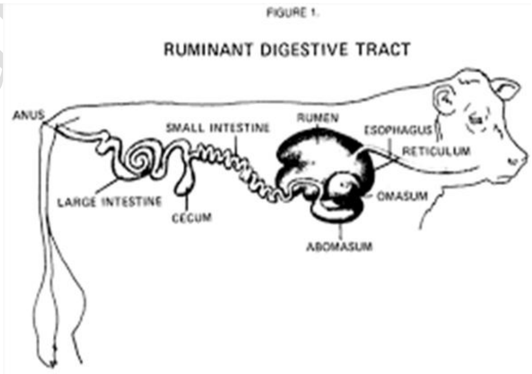
Caece in Vertebrates

Caece

- The caecum is a short, pouch-like part of the large intestine between the ascending colon and vermiform appendix.
- In ruminants microorganisms attack the food before gastric digestion. but In typical non ruminant herbivores microbial action on cellulose occurs after digestion.
- Rabbits, horses, and rats digest cellulose by maintaining a population of microorganisms in their unusually large caecum
- Adding to this efficiency, a few non-ruminant herbivores, such as mice and rabbits.



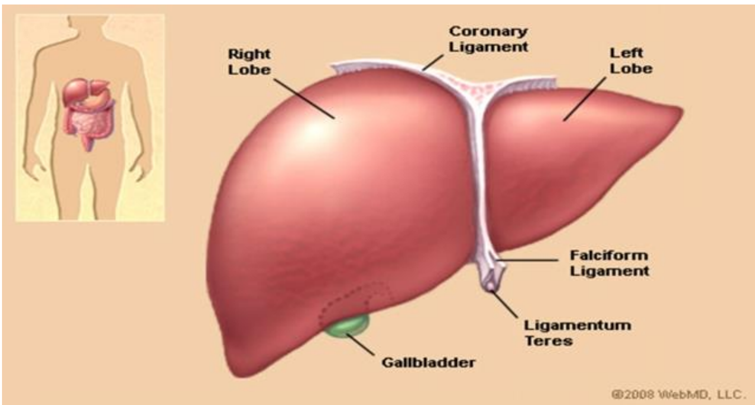




Livers in Vertebrates

The Liver

- In humans, the liver is an organ located in the right upper quadrant of the abdomen, below the diaphragm.
- Liver is found only in vertebrates.

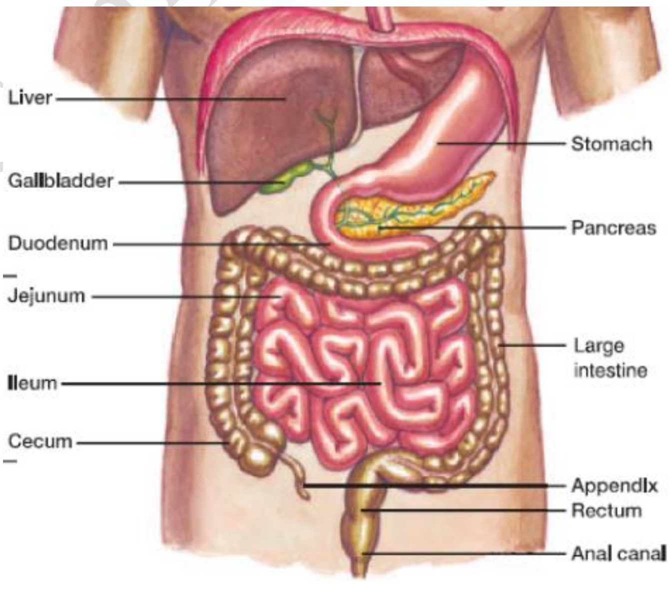


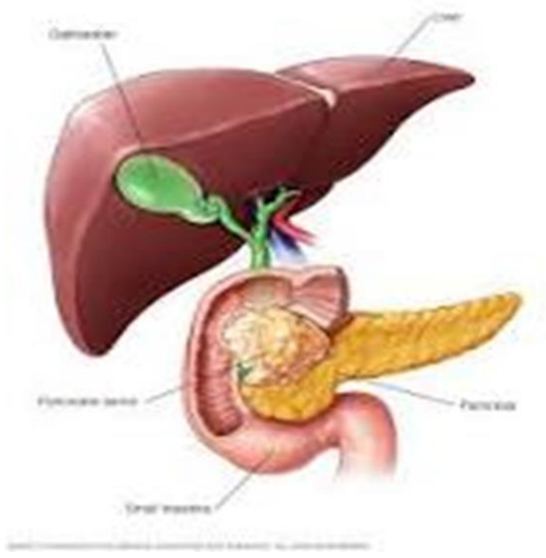
Functions of Liver

- The liver manufactures bile.
- Bile is a fluid containing bile salts and bile pigments.
- Bile salts play an important role in the digestion of fats, although they are not digestive enzymes.
- They emulsify dietary fat, breaking it into small globules (emulsification) on the surface of which the fat-digesting enzyme lipase can function.
- RBCs are phagocytized to form Bile Pigments in the spleen, liver and red bone marrow.
- Phagocytosis cleaves the hemoglobin molecule, releasing iron, and the remainder of the molecule is converted into pigments that enter the circulation.
- These pigments are subsequently extracted from the circulation in the liver and excreted in the bile as bilirubin (“red bile’’) and biliverdin (“green bile’’).
- Liver detoxifies various metabolites.
- Liver synthesizes proteins and produces bio chemicals necessary for digestion and growth.
- Destruction of RBCs and formation of bile pigments.
- Protein metabolism
- Synthesis of plasma proteins
- Enzyme synthesis.
- Conversion of ammonia to urea.
- Carbohydrate metabolism
- Fat metabolism
- Removal or excretion of drugs
- Gallbladder is a small hollow organ where bile is stored and concentrated before it is released into the small intestine.
- The structure and position of the gallbladder can vary significantly among animal species.
- Because of the importance of bile in fat digestion, the gallbladder is relatively large in carnivores and vertebrates.
- Gallbladder is much reduced or absent in bloodsuckers, such as the lamprey, and in animals that feed primarily on plant food (e.g., some teleosts, many birds, and rats).

Pancreata in Vertebrates

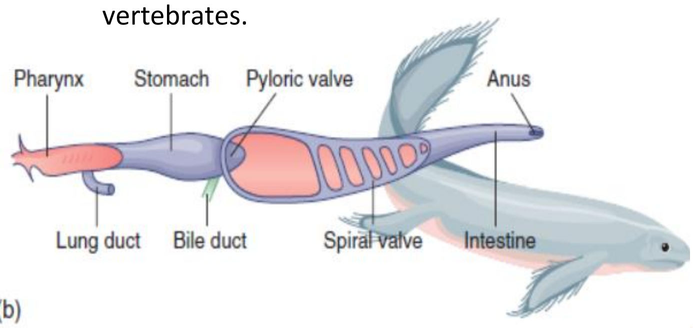
- The pancreas is a gland organ.
- Pancreas produces enzymes, or digestive juices, and are released into the small intestine.
- There, it continues breaking down food that has left the stomach.
- The pancreas also produces the hormones:
  - i) Insulin and
  - ii) Glucagon
- These hormones are secreted into the bloodstream, where they regulates the body's glucose or sugar level.
- Every vertebrate has a pancreas, however, in lampreys and lungfishes it is embedded in the wall of the intestine and is not a visible organ.
- Both endocrine and exocrine tissues are present, but the cell composition varies.
- Pancreatic fluid containing many enzymes empties into the small intestine via the pancreatic duct.





Intestines in Vertebrates

- The intestines are a long, continuous tube running from the stomach to the anus.
- Most absorption of nutrients and water takes place in the intestines.
- The intestines include the small intestine, large intestine, and rectum.
- The small intestine (small bowel) is about 20 feet long and about an inch in diameter.
- The configuration and divisions of the small and large intestines vary greatly among vertebrates.
- Intestines are closely related to the animal's type of food, body size, and levels of activity.
- For example, cyclostomes, chondrichthian fishes, and primitive bony fishes have short, nearly straight intestines that extend from the stomach to the anus.
- In more advanced bony fishes, the intestine increases in length and begins to coil.
- The intestines are moderately long in most amphibians and reptiles.
- In birds and mammals, the intestines are longer and have more surface area than those of other tetrapods.
- Birds typically have two ceca, and mammals have a single cecum at the beginning of the large intestine.
- The large intestine is much longer in mammals than in birds, and it empties into the cloaca in most vertebrates.



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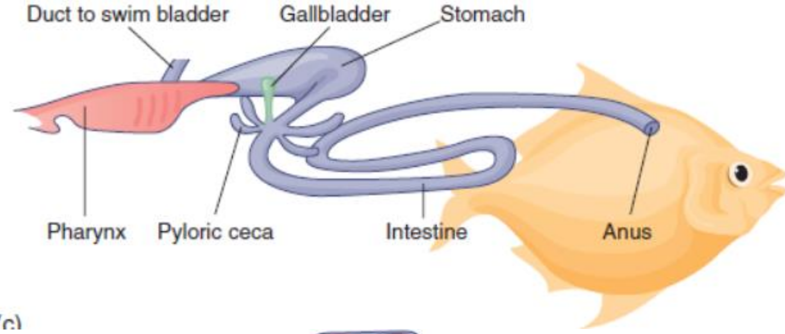

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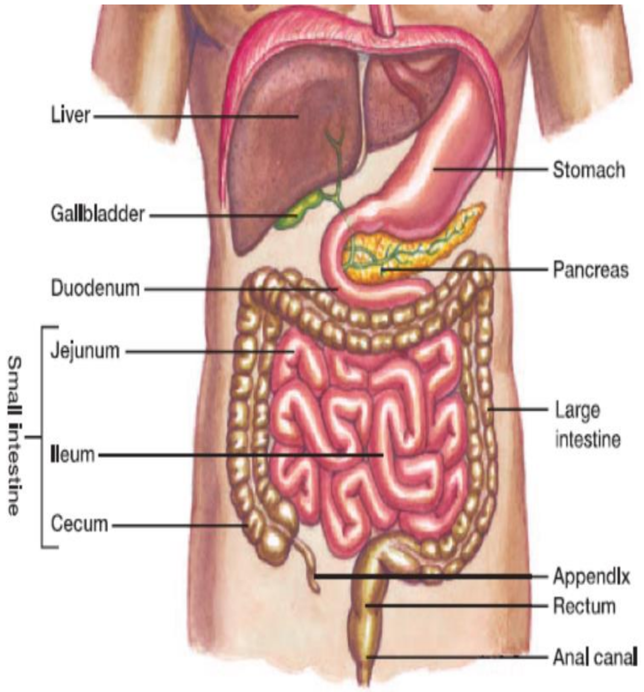

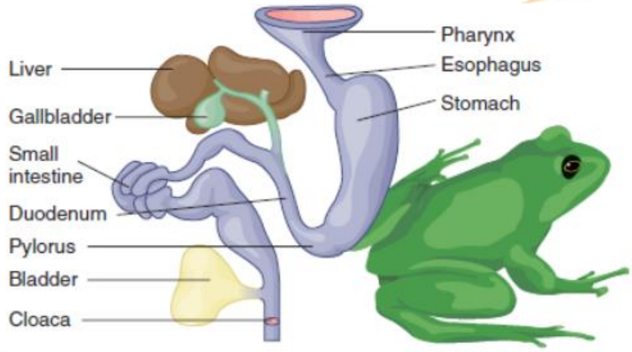

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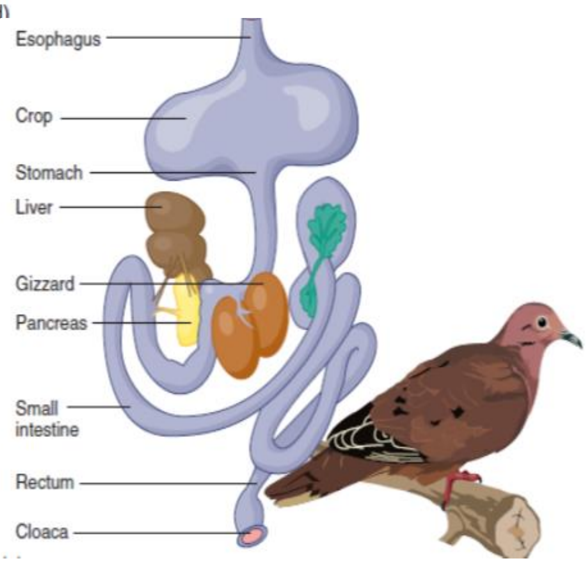
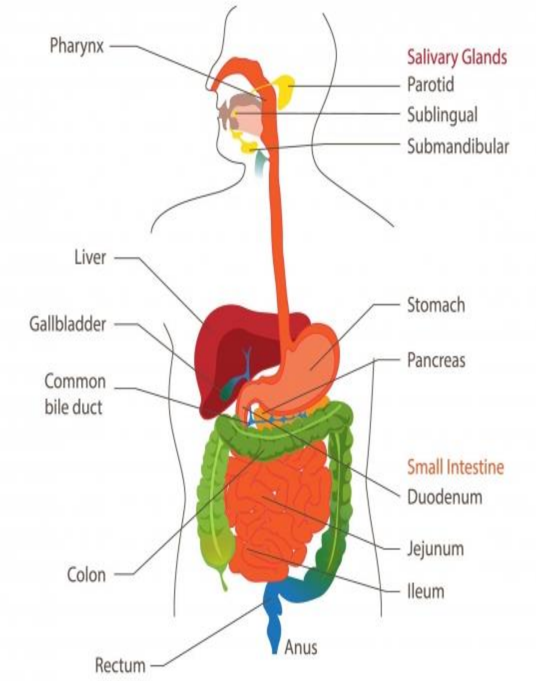


Mammalian Digestive System

The Mammalian Digestive System

- **The digestive system of an omnivore has the mechanical and chemical ability to process many kinds of foods.**
- **Humans, pigs, bears, raccoons, and a few other mammals are omnivores.**



Major Organs and Parts of the Human Digestive System.

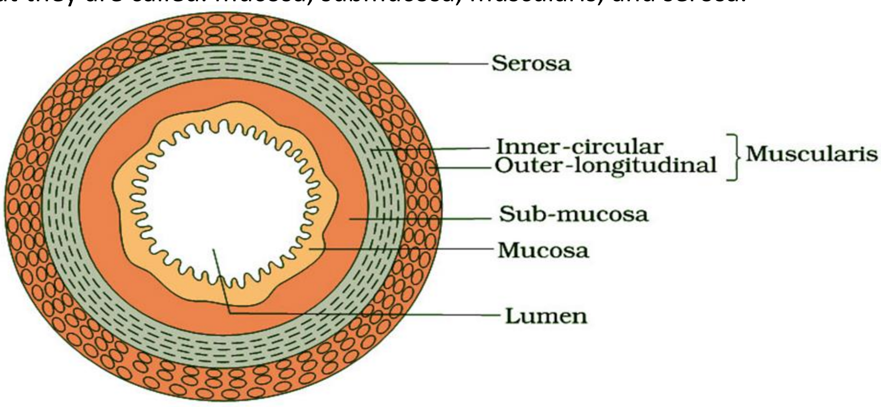
- Food passes from the mouth through the pharynx and esophagus to the stomach.
- From the stomach, it passes to the small intestine, where nutrients are broken down and absorbed into the circulatory and lymphatic systems.
- Nutrients then move to the large intestine, where water is reabsorbed, and feces form.
- Feces exit the body via the anal canal.
- In mammals the process of digestion and absorption of nutrients includes:

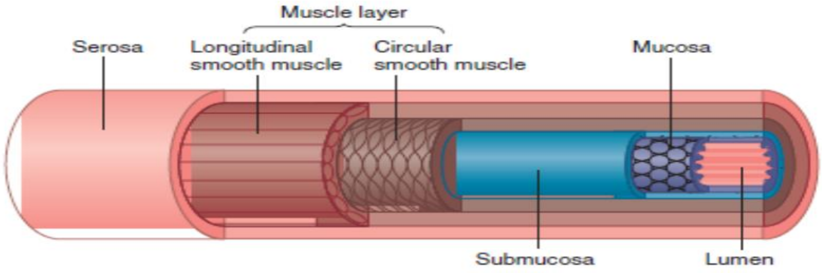
  1. **Ingestion**—eating.
  2. **Peristalsis**—the involuntary, sequential muscular contractions that move ingested nutrients along the digestive tract.
  3. **Segmentation**—mixing the contents in the digestive tract.
  4. **Secretion**—the release of hormones, enzymes, and specific ions and chemicals that take part in digestion.
  5. **Digestion**—the conversion of large nutrient particles or molecules into small particles or molecules.
  6. **Absorption**—the passage of usable nutrient molecules from the small intestine into the bloodstream and lymphatic system for the final passage to body cells.
  7. **Defecation**—the elimination from the body of undigested and unabsorbed material as waste.

Layers of Mammalian Gastro Intestinal (GI) Tract

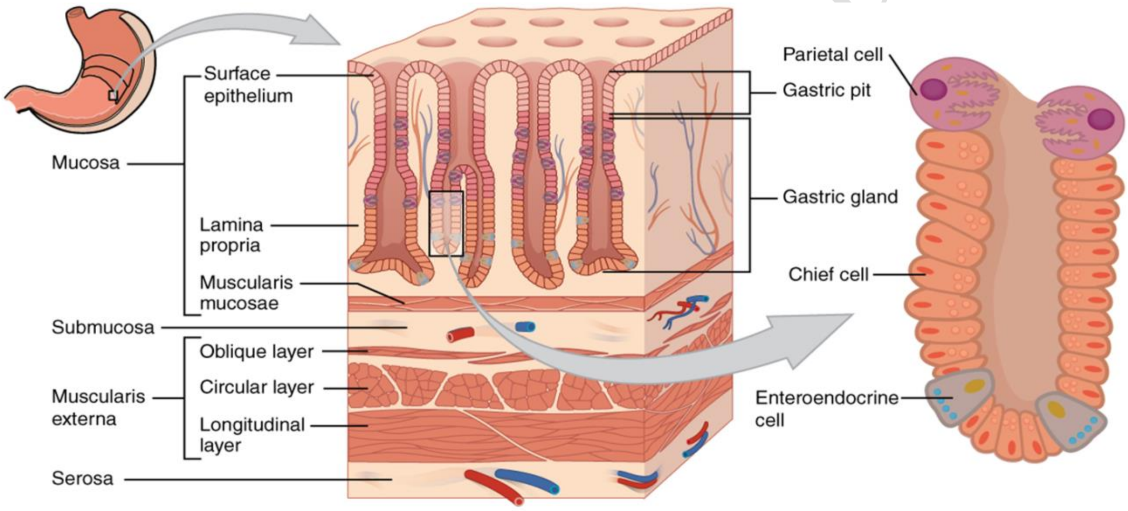
Layers of GI Tract

- The GI tract is composed of four layers.
- Each layer has different tissues and functions.
- From the inside out they are called: mucosa, submucosa, muscularis, and serosa.



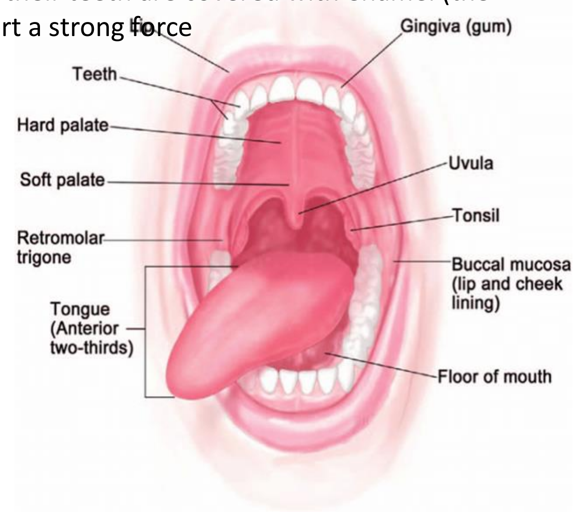


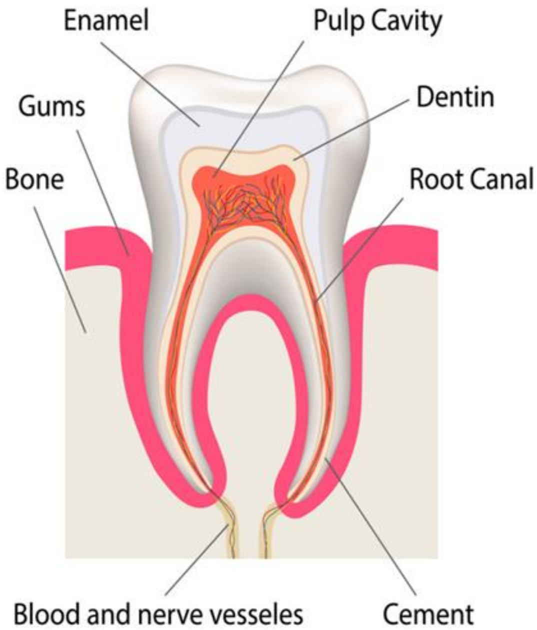
- The mucosa is the innermost layer, and functions in absorption and secretion.
- It is composed of epithelium cells and a thin connective tissue.
- The mucosa contains specialized goblet cells that secrete sticky mucus throughout the GI tract.
- On the mucosa layer, small finger-like projections called villi and microvilli help to increase surface area for nutrient absorption.
- the submucosa is the layer of connective tissue that supports the mucosa, as well as joins the mucosa to the bulk of underlying smooth muscle.
- The muscularis, or muscularis externa, consists of an inner circular muscular layer and a longitudinal outer muscular layer.
- The coordinated contractions of these layers is called peristalsis, which propels the food through the GI tract.
- Serosa. This structure consists of connective tissue covered by a simple squamous epithelium

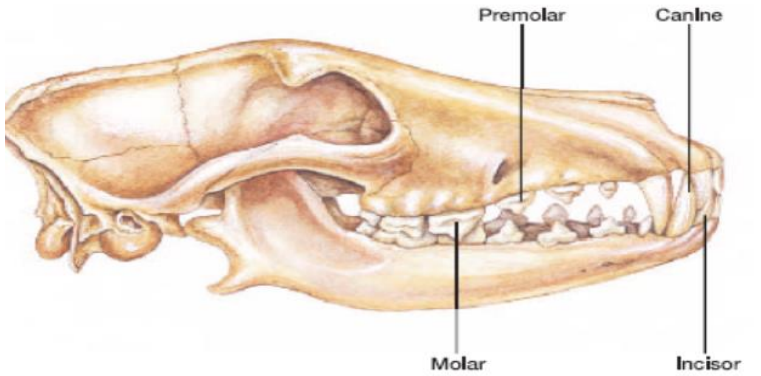


Human Oral Cavity

- A pair of lips protects the oral cavity (mouth).
- The lips are highly vascularized, skeletal muscle tissue with an abundance of sensory nerve endings.
- Lips help retain food as it is being chewed and play a role in phonation (the modification of sound).
- The oral cavity is bounded by the roof, the hard and soft palate the floor of the mouth under the tongue, the side cheeks and the small area behind the wisdom teeth.
- The oral cavity contains the tongue, gums and teeth.
- Mammals can mechanically process a wide range of foods because their teeth are covered with enamel (the hardest material in the body) and because their jaws and teeth exert a strong force
- In mammals there are four types of teeth:
    - Incisors, Canine, Premolars and Molars.







- Saliva moistens food, binds it with mucins (glycoproteins), and forms the ingested food into a moist mass called a bolus.
- Saliva also contains bicarbonate ions (HCO_3), which buffer chemicals in the mouth, the enzyme lysozyme, which kill microorganisms.
- It also contributes an enzyme (amylase) necessary for the initiation of carbohydrate digestion.

Digestion in Oral Cavity

Following are the main functions of the oral cavity:

- Selection of food
- Grinding or mastication of food
- Lubrication and
- Digestion

Selection of Food:

- Food is selected by the senses of smell, sight and taste.

Grinding of food:

- After selection, food is ground by means of molar teeth into smaller pieces.

This is useful because:

- Esophagus allows only smaller pieces to pass through
- Smaller pieces have much more surface for the enzymes to enter.

Lubrication and Digestion:

- These are the chief functions of the oral cavity accomplished by saliva.
- Saliva is secreted by three pairs of salivary glands:
- Sublingual, sub maxillary and parotid.

Saliva produced by these glands contains:

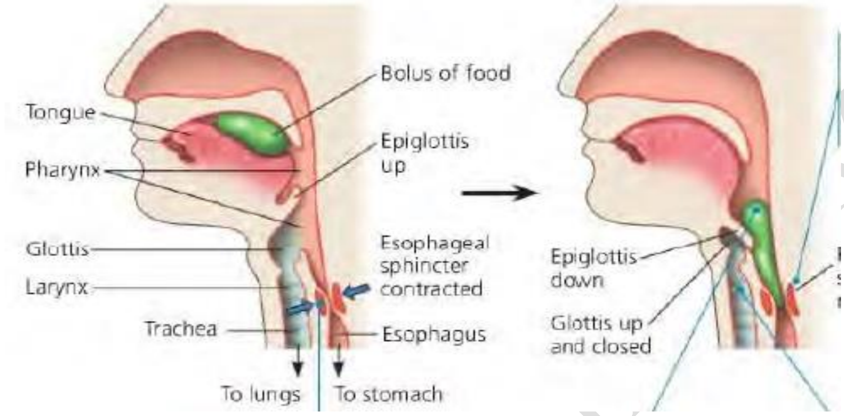
- Water and mucus - serves to moisten and lubricate food.
- Sodium bicarbonate which buffer chemicals in mouth,.
- An enzyme, lysozyme, and thiocyanate ions (SCN) that kill microorganisms.
- Carbohydrate digesting enzyme –amylase or ptyalin for the initiation of carbohydrate digestion.
- Starch and Glycogen--Maltose.
- Fresh saliva is alkaline with pH nearly 8, quickly loses CO_2 and gets to pH 6.

Swallowing of Food

- Masticated, softened, partly digested and slimy food mass is rolled into bolus.
- Bolus is then pushed back of the mouth by the action tongue and muscles of the pharynx.

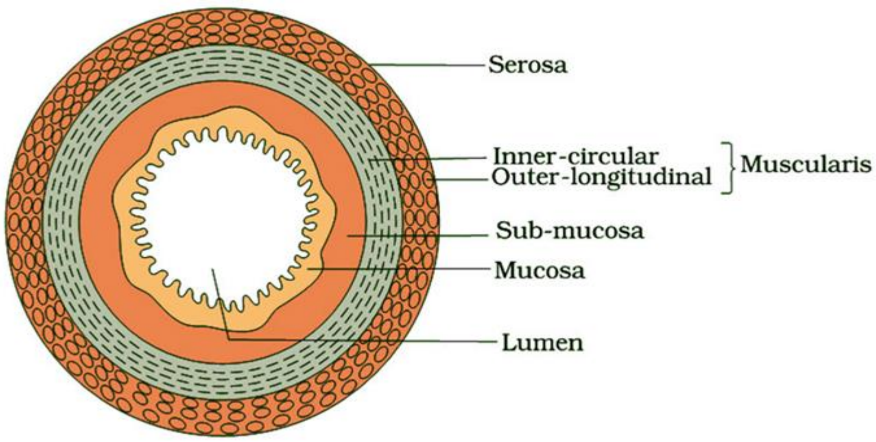
Events of Swallowing

- The tongue moves upward and backward forcing the bolus to the back of the mouth cavity.
- The backward movement of the tongue pushes the soft palate up and closes the nasal opening at the back.
- At the same time the tongue forces the epiglottis into more or less horizontal position thus closing the opening of the wind pipe.
- The food or bolus is then diverted safely down the esophagus.
- The beginning of swallowing action is voluntary but once the food reached the back of the mouth, swallowing becomes automatic.
- The food is then forced down the esophagus by peristalsis.



Gastrointestinal Motility

- As with any organ, the function of the gastrointestinal tract is determined by the type of tissues it contains.
- Most of the mammalian gastrointestinal tract has the same anatomical structure along its entire length.
- From the outside inward is a thin layer of connective tissue called the serosa.
- The serosa forms a moist epithelial sheet called the peritoneum.
- This peritoneum lines the entire abdominal cavity and covers all internal organs.

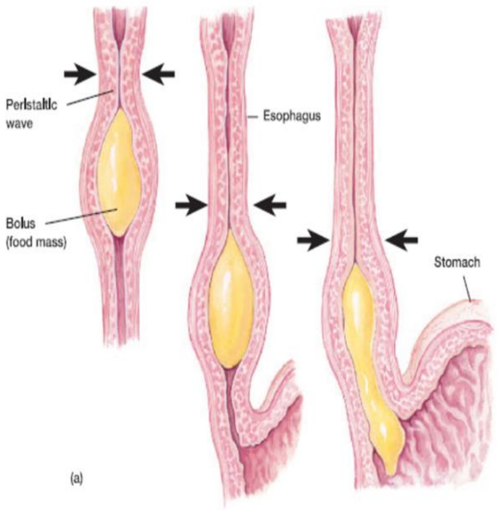


- Next are the longitudinal smooth-muscle layer and circular smooth-muscle layer.
- Underneath this muscle layer is the submucosa.
- The submucosa contains connective tissue, blood, and lymphatic vessels.
- The mucosa faces the central opening, which is called lumen.
- The coordinated contractions of the muscle layers of the gastrointestinal tract mix the food material with various secretions and move the food from the oral cavity to the rectum.
- The two types of movement involved are peristalsis and segmentation.

Peristalsis and Segmentation

Peristalsis:

- The characteristic involuntary movements of the digestive tract by which food moves along the cavity of the canal.
- It comprises relaxation of circular smooth muscles, then their contraction behind the chewed material to keep it from moving backward, then longitudinal contraction to push it forward.
- During peristalsis the food advances through the GI tract when the rings of circular smooth muscle contract behind it and relax in front of it.
- The small and large intestines also have rings of smooth muscles that repeatedly contract and relax.

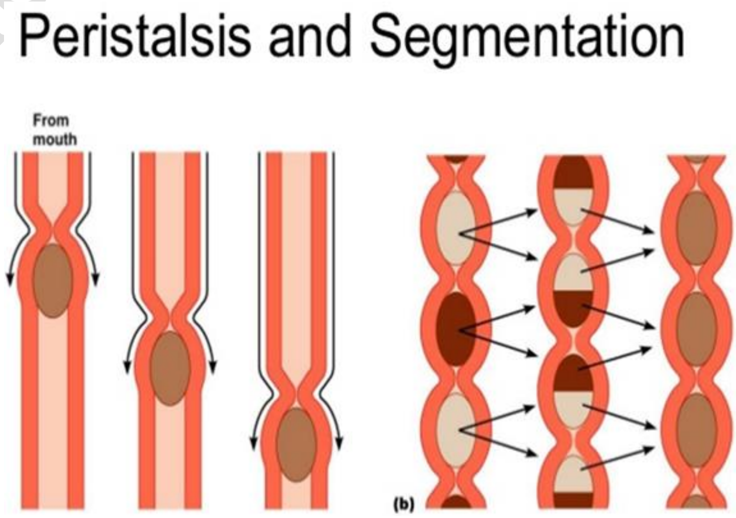


Segmentation

- In segmentation, simultaneous muscular contractions of many sections of the intestine help mix nutrients with digestive secretions.
- This is coordinated contractions of the muscle layers of the GI tract.
- This creates an oscillating back-and-forth movement in the same place, called segmentation.
- This movement mixes the food with digestive secretions and increases the efficiency of absorption.

Antiperistalsis

- The reverse peristalsis is called Antiperistalsis, which occurs occasionally.
- These movements cause the passage of food from the intestine back into the stomach or even into the mouth.
- This is also called vomiting.



PERISTALSIS
VERSUS
SEGMENTATION

PERISTALSIS	SEGMENTATION
The involuntary contraction and relaxation of muscles of the intestine, creating wave-like movements, pushing the contents of the canal forward	The back and forth smooth muscle contractions mainly in the small intestine for the smooth muscle contractions
Mainly occurs in the esophagus	Mainly occurs in the small and large intestine
Occurs by the contractions of the circular muscles	Occurs due to the rhythmic contractions of the longitudinal muscles
A one-way motion in the caudal direction	Responsible for the movement in both directions, allowing a greater mixing
Results in high-speed propagation of food	Results in slow propagation of food

Control of Gastrointestinal Tract Motility

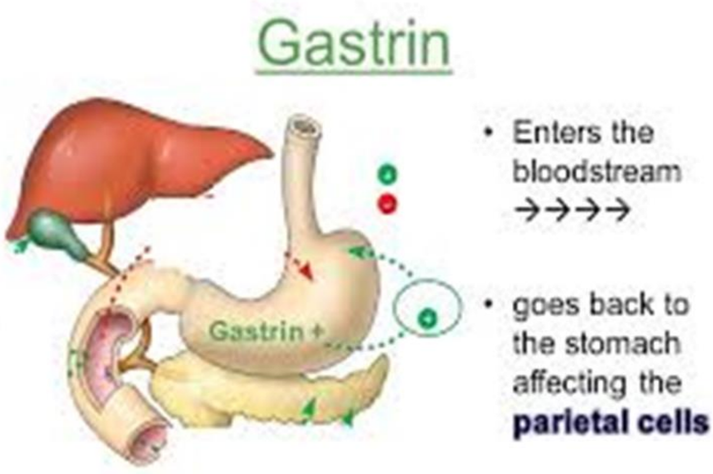
- Control of gastrointestinal activity is based on the volume and composition of food in the lumen of the gut.
- Ingested food distends the gut and stimulates mechanical receptors in the gut wall.
- In addition, digestion of carbs, lipids, and proteins stimulates various chemical receptors in the gut wall.

Nervous Control

- Signals from these mechanical and chemical stimuli travel through nerve plexuses in the gut wall to control the muscular contraction that leads to peristalsis and segmentation.
- This also controls the secretion of various substances (e.g., mucus, enzymes) into the gut lumen.
- In addition to this local control, long-distance nerve pathways connect the receptors and effectors with the CNS.
- Either or both of these pathways function to maintain homeostasis in the gut.

Endocrine Control

- The endocrine cells of the gastrointestinal tract also produce hormones that help regulate secretion, digestion, and absorption. (Gastrin, Secretin)



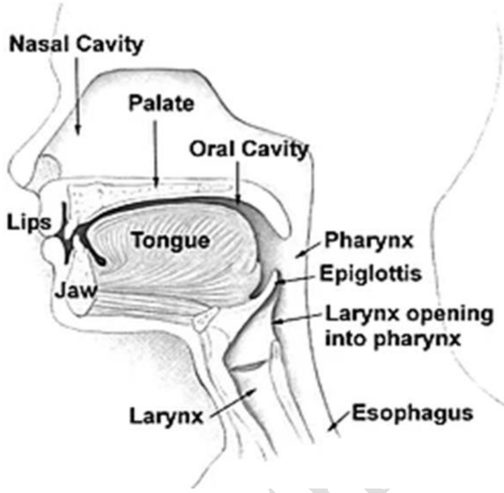
Pharynx in Vertebrates

Pharynx

- It is the common passageway for both the digestive and respiratory tracts.
- How both air and swallowed foods and liquids pass from the mouth into the respiratory and digestive tract respectively?
- It is the epiglottis that controls the traffic.
- Initiation of the swallowing reflex can be voluntary, but most of the time it is involuntary.
- When swallowing begins, sequential, involuntary contractions of smooth muscles in the walls of the esophagus propel the bolus or liquid to the stomach.
- Neither the pharynx nor the esophagus contributes to digestion.

The epiglottis

- The epiglottis temporarily seals off the opening (glottis) to the trachea so that swallowed food does not enter the trachea.



Stomach in Vertebrates

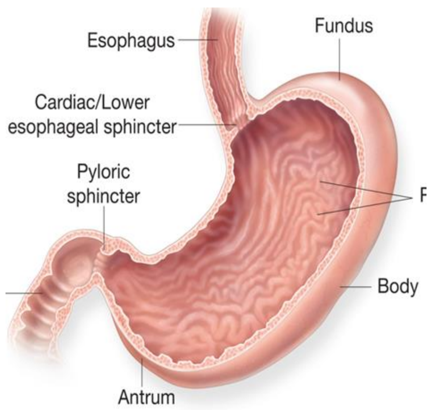
Structure of Stomach

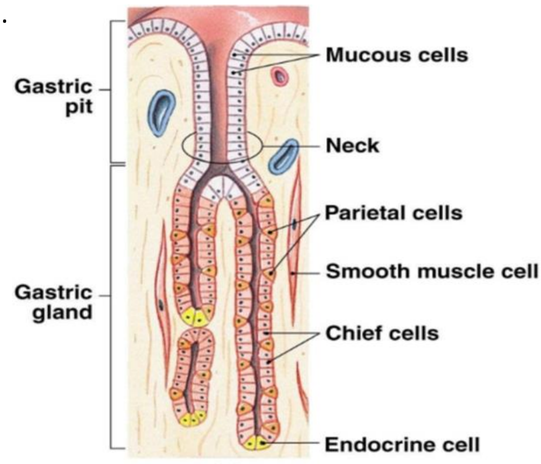
- The mammalian stomach is a muscular, distensible sac.
- The stomach is made up of an inner mucous membrane containing thousands of gastric glands.
- These gastric glands are composed of three types of cells:
- Parietal cells, secrete a solution containing HCl.
- Chief cells secrete pepsinogen, the precursor of the enzyme pepsin.
- Both of the cells are in the pits of the gastric glands.
- Mucous cells secrete mucus that coats the surface of the stomach and protects it from the HCl and digestive enzymes.
- The esophagus and mouth have a much thinner mucous-cell layer.

Functions of Stomach

The mammalian stomach has three main functions.

- 1. Stores and mixes the food bolus received from the esophagus.
- 2. Secretes substances (enzymes, mucus, and hydrochloric acid (HCl) that start the digestion of proteins.
- 3. Helps control the rate at which food moves into the small intestine via the pyloric sphincter.
- 4. Endocrine cells in stomach mucosa release the hormone, gastrin, which travels to target cells in the gastric glands, further stimulating them to release gastric juice.





- When the bolus of food enters the stomach, it distends the walls of the stomach.
- This distention, as well as the act of eating, causes the gastric pits to secrete HCl and pepsinogen.
- The H+ ions cause pepsinogen to be converted into the active enzyme pepsin.
- As pepsin, mucus, and HCl mix with and begin to break down proteins, smooth mucosal muscles contract and vigorously churn and mix the food bolus.
- About three to four hours after a meal, the stomach contents have been sufficiently mixed and forms semiliquid mass called chyme.
- The pyloric sphincter regulates the release of the chyme into the small intestine.
- When the stomach is empty, peristaltic waves cease, however, after about 10 hours of fasting, new waves may occur in the upper region of the stomach.
- These waves can cause “hunger pangs’’ as sensory nerve fibers carry impulses to the brain.

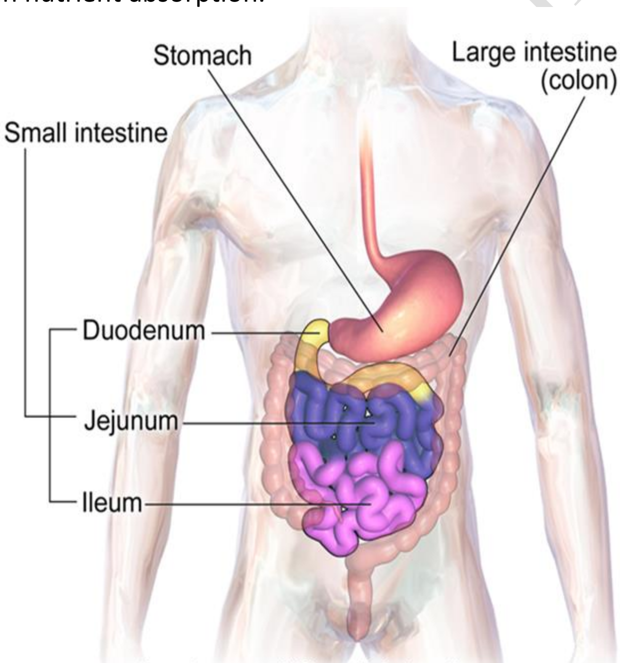
Small Intestine
(Parts and Structure)

Small Intestine

- The human small intestine is about 4 cm in diameter and 7 to 8 m in length.
- Length of human small intestine is intermediate between the small intestines of typical carnivores and herbivores of similar size.
- It reflects the human’s omnivorous eating habits.

The small intestine has three parts:

1. Duodenum
   - It is about 6 m in length and functions primarily in digestion.
2. Jejunum and Ileum.
   -Both function in nutrient absorption.



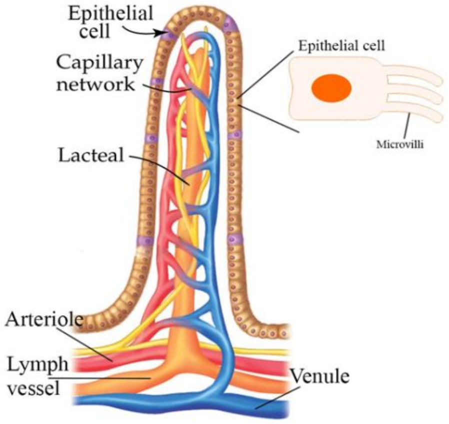
Anatomy of Small Intestine

- There is no clear border between the jejunum and the ileum.
- Histologically, the jejunum differs from the rest of the small intestine by the absence of Brunner’s glands (which are present in the duodenum and Peyer’s patches (which are present in the ileum .
- The Brunner’s glands produce alkaline mucus, which neutralizes acid from the stomach as it enters the duodenum.
- Peyer’s patches or nodules of lymphoid follicles in the mucus membrane that lines small intestine, the Ileum.
- The wall of the jejunum contains the following features that increase its surface area:
  - Circular folds;
  - Villi,
  - Microvilli.

- These features are also found in the ileum, though with slight differences.
- The small intestine has many circular folds and minute projections called Villi on the inner gut surface.
- This is to increase the surface for absorption.
- Simple columnar epithelial cells, each bearing numerous microvilli, cover the villi .
- These minute projections are so dense that the inner wall of the human small intestine has a total surface area of approximately 300 m^2—the size of a tennis court.

Structure of Villus

- A single villus contains a central capillary network and a lymphatic lacteal, both of which transport nutrients absorbed from the lumen of the intestine.
- The plasma membrane of the simple columnar epithelial cells covering the villi fold into microvilli, further increase the surface area.



Digestion in Small Intestine

Duodenum:

- When chyme passes from the stomach into duodenum, its acidity stimulates the release of three secretions:
  1. *Digestive enzymes*
  2. *Pancreatic enzymes*
  3. *Bile*

Intestinal Enzymes:

- *Enterokinase* Converts inactive trypsinogen into active trypsin.
- *Lactase* Digests lactose into glucose and galactose.
- *Maltase* Digests maltose into glucose.
- *Peptidase* Digests polypeptides into amino acids.
- *Sucrase* digests sucrose into glucose and fructose.

Pancreatic Enzymes

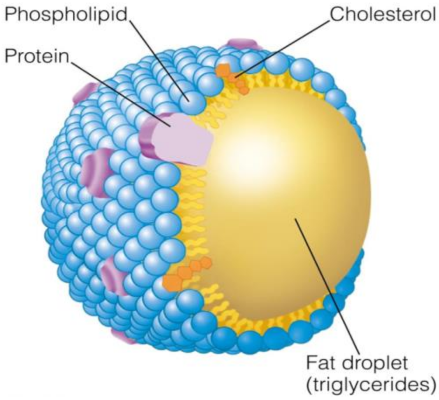
- *Pancreatic Amylase*- Digests starch into maltose
- *Chymotrypsin*- Digests proteins into peptides and amino acids
- *Lipase*- Digests lipids into fatty acids and glycerol (requires bile salts).
- *Nuclease*- Digests nucleic acids into mononucleotides.
- *Trypsin*- Digests proteins into peptides and amino acids.

Liver

- Secretes Bile which contains no enzyme.
- It emulsifies lipids; activates lipase.
- In the duodenum, digestion of carbohydrates and proteins is completed, and most lipids are digested.
- The jejunum and ileum absorb the end products of digestion (amino acids, simple sugars, fatty acids, glycerol, nucleotides and water).

Absorption of Foods:

- Much of this absorption involves active transport and the sodium dependent ATPase pump.
- Sugars and amino acids are absorbed into the capillaries of the villi.
- Free fatty acids enter the epithelial cells of the villi and recombine with glycerol to form triglycerides.
- The triglycerides are coated with proteins to form small droplets called chylomicrons, which enter the lacteals of villi.



Role of Pancreas in Digestion

- The pancreas is an organ that lies just ventral to the stomach and has both endocrine and exocrine functions.
- Exocrine cells secrete digestive enzymes into the pancreatic duct, which merges with the hepatic duct to form a common bile duct that enters the duodenum.
- The pancreas also secretes bicarbonate (HCO_3) ions that help neutralize the acidic food residue coming from the stomach.
- Bicarbonate raises the pH from 2 to 7 for optimal digestion.
- Without such neutralization, pancreatic enzymes could not function.
- **Amylase:** Digests starch into maltose
- **Chymotrypsin:** Digests proteins into peptides and amino acids
- **Pancreatic Lipase:** Digests lipids (triglycerides) into smaller, absorbable glycerol and free fatty acids.
- **Nuclease:** Digests nucleic acids into mononucleotides,
- **Trypsin:** Digests proteins into amino acids.

Role of Liver in Digestion

- The liver is the largest organ in the mammalian body, is just under the diaphragm.
- It is composed of millions of specialized cells called hepatocytes.
- They also manufacture the blood proteins, prothrombin and albumin.
- Major metabolic functions of the liver include:

1. Removal of amino acids from organic compounds.
2. Urea formation from proteins and conversion of excess amino acids into urea to decrease body levels of ammonia.
3. Synthesis of nonessential amino acids.
4. Conversion of galactose and fructose to glucose.
5. Oxidation of fatty acids.
6. Manufacture of plasma protein, the albumin.
7. Formation of fetal RBCs.
8. Destruction of worn-out RBCs.
9. Synthesis of the blood-clotting agents prothrombin and fibrinogen from amino acids.
10. Formation of lipoproteins, cholesterol, and phospholipids (essential cell membrane components).
11. Conversion of carbohydrates and proteins into fat.
12. Modification of waste products, toxic drugs, and poisons (detoxification).
13. Synthesis of vitamin A from carotene, and with the kidneys, participation in the activation of vitamin D.
14. Maintenance of a stable body temperature.
15. Liver is the major heat producer in a mammal’s body.
16. Manufacture of bile salts, which are used for the emulsification of fats in the small intestine.

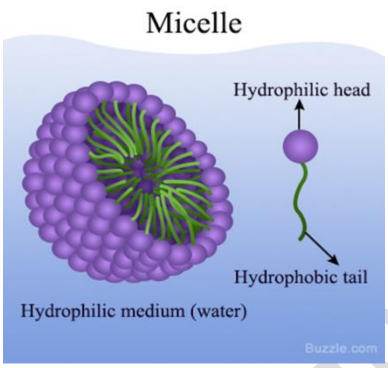
Main storage center

- The liver stores glucose in the form of glycogen, and with the help of insulin and enzymes, converts glycogen back into glucose as the body needs it.
- The liver also stores fat-soluble vitamins (A, D, E, and K), and minerals, such as iron, from the diet.
- The liver can also store fats and amino acids, and convert them into usable glucose as required.

Gallbladder and Bile

Role of Gall Bladder

- The gallbladder is a small bag near the liver.
- The gallbladder stores the greenish fluid, the bile that the liver cells continuously produce.
- Bile is very alkaline and contains pigments e.g. biliverdin (green) and bilirubin (Red)
- Bile also contain salts that act as detergents to emulsify fats and aid in fat digestion and absorption.
- Bile salts also combine with the end products of fat digestion to form micelles.
- Micelles are lipid aggregates (fatty acids and glycerol) with a surface coat of bile salts.
- Because they are so small, they can cross the microvilli of the intestinal epithelium.

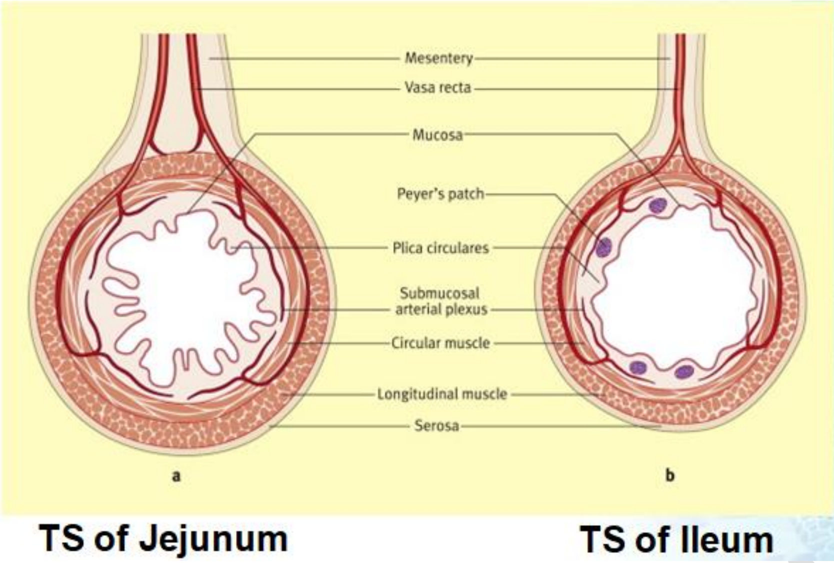


- Micelles are lipid molecules that arrange themselves in a spherical form in aqueous solutions.
- The formation of a micelle is a response to the amphipathic nature of fatty acids, meaning that they contain both hydrophilic regions (polar head groups) as well as hydrophobic regions (the long hydrophobic chain).

Digestion in Jejunum and Ileum

- The jejunum is the second portion of the small intestine extending from duodenum to ileum.
- Jejunum makes up about two-fifths of the small intestine.
- It is about 2.4 m in length.
- Lower three fifth of the small intestine from jejunum to ileocolic sphincter is the ileum.
- The main function of the jejunum is absorption of important nutrients-sugars, fatty acids, and amino acids.
- Nutrients absorbed by the jejunum enter the bloodstream, where they can then be distributed to the organs of the body.
- The food which escapes undigested from the duodenum is completely digested in jejunum and ileum by a group of following enzymes.
- These enzymes, their substrates and final products are:
  i) Polypeptides -- *Amino peptidase* Dipeptides
  ii) Dipeptides --- *Erypsin*--- Amino acids.
  iii) Fats---*Lipase*---- Fatty acids + Glycerol
  iv) Maltose-- *Maltase*– Glucose
  v) Lactose – *Lactase*– Glucose and Galctose.

- The enzymes which complete the digestive process are NOT secreted into the lumen of the intestine.
- In fact these final processes take place in the membranes of the microvilli of the epithelial mucosa because the enzymes are located within the cell membranes.
- The end products of digestion are then liberated into the lumen of intestine on their way to blood stream.
- The function of the ileum is mainly to absorb vitamin B12, bile salts, and any products of digestion that were not absorbed by the jejunum.



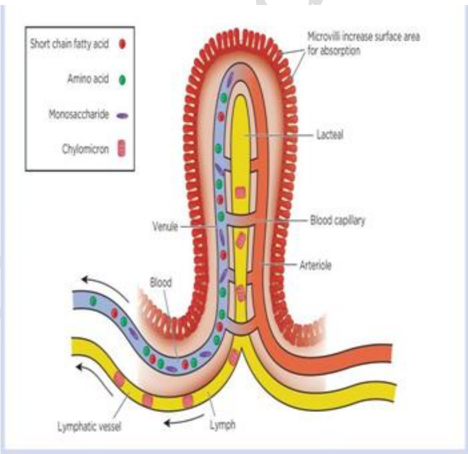
Structure and Function of Villi

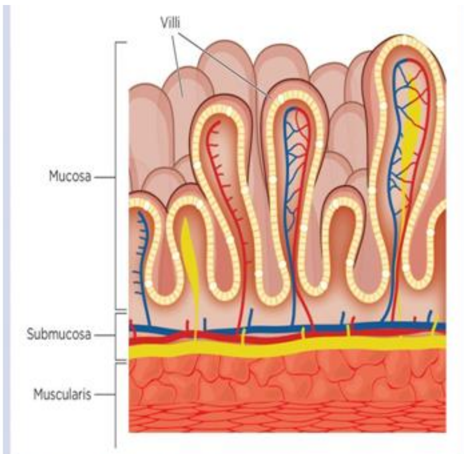
Villi

- Located in the circular folds measuring 0.5-1mm in length, finger-like projections known as villi extend into the intestinal lumen available for nutrient absorption. Each villus contains a:
- Capillary bed – comprising an arteriole and a venule.
- Lymphatic capillary – central lacteal.
- The venules allow glucose and amino acids to be absorbed directly into the bloodstream, while products from the breakdown of lipids (fatty acids and glycerol) are absorbed into the lymphatic system via the lacteals.

Microvilli

- The mucosal epithelial cells have thin, hair-like extensions about 1µm (0.001mm) in length, jutting out into the intestinal lumen.
- These tiny projections are known as microvilli and there are approximately 200 million of them per $1mm^2$.
- Microscopically, they appear as a mass of bristles and are, therefore, termed the brush border.
- Fixed to the surface of the microvilli are a series of enzymes that finish chemical digestion.



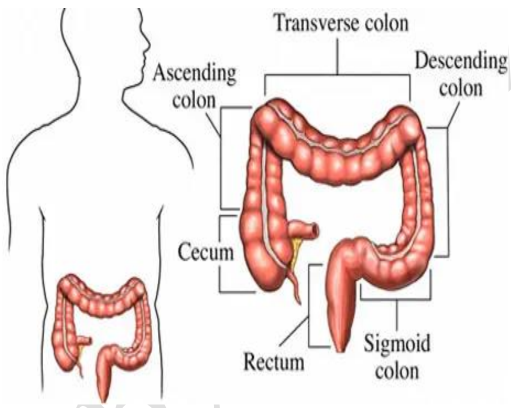


Absorption of Digested Food

- Nearly all absorption of the products of digestion takes place in the ileum through Villi.
- Each villus is richly supplied with blood capillaries and a vessel called lacteal of lymphatic system with a covering of epithelial cells having microvilli.
- The total area of absorption becomes extensively large due to in-foldings, villi and microvilli.
- Monosaccharides and amino acids are absorbed either by diffusion or active transport into blood capillaries through microvilli.
- Some of the fatty acids and glycerol are also absorbed into the blood stream.
- However, a large proportion of fatty acids and glycerol enter the epithelial cells of villi where they recombine into fats which then enter the lacteals.
- Proteins present in lymph vessels combine with fat molecules to form lipo-protein droplets.
- These lipoprotein molecules subsequently hydrolyzed by blood plasma enzyme back to fatty acids and glycerol.
- These molecules are then absorbed by the body cells where they are used in respiration or stored as fats in liver, muscles or under the skin

Large Intestine

- Large Intestine is composed of caecum, colon and rectum.
- Caecum is blind sac that projects from the ileum and colon.
- From the caecum there arises a finger-like process called appendix.



Appendicitis:

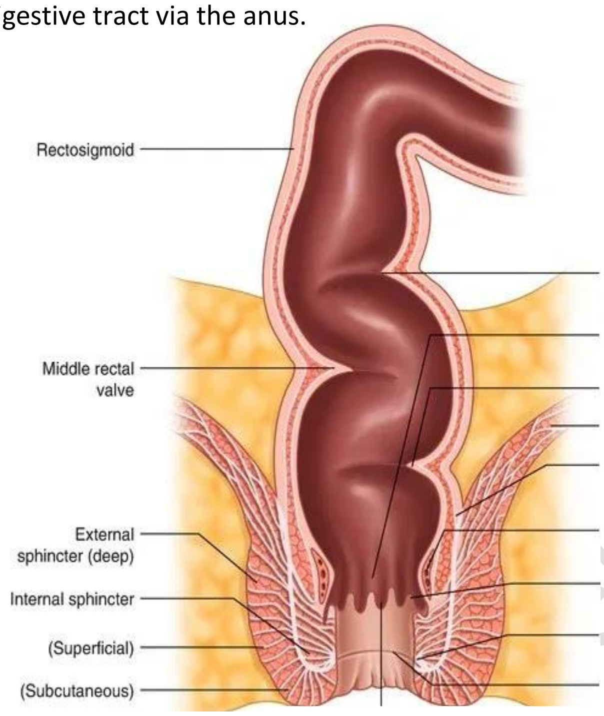
- The appendixes sometimes get inflamed due to entrapping and the putrefaction of food causing appendicitis.
- Appendix has to remove surgically in many instances.
- The material that passes from the small intestine to the large intestine contains:
    - Water
    - Dissolved salts
    - Undigested material
    - Water and salts are absorbed into blood while undigested material is rejected as feces.
- Large intestine also harbors a large population of useful bacteria that synthesize some vitamins especially Vitamin K which absorbed in blood.

Composition of Fecal Matter

Fecal matter is composed of:

2. Undigested material
3. Bacteria
4. Plant fibers
5. Sloughed off mucosal cells
6. Mucus
7. Bile pigments
8. Metabolic wastes
9. Water

- Normally human feces are semisolid, with a mucus coating.
- In the medical literature, the term "stool" is more commonly used than "feces".
- Human feces together with human urine are collectively referred to as human waste or human excreta.
- Defecation is the final act of digestion, by which organisms eliminate solid, semisolid, or liquid waste material from the digestive tract via the anus.



Rectum

Rectal Sinus

Some Common Diseases Related to Nutrition

Following are some common diseases related to nutrition and digestive system:

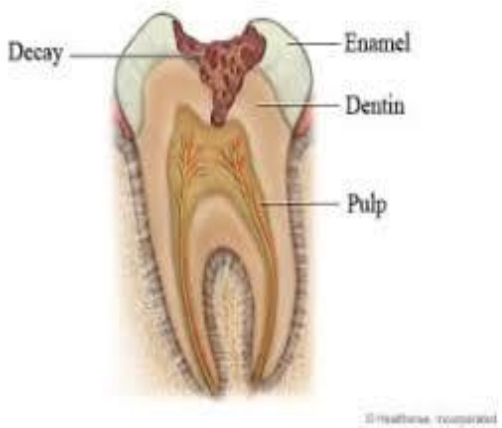
- Dental Caries
- Dyspepsia
- Food poisoning
- Anorexia Nervosa
- Obesity
- Piles or Hemorrhoids

Dental Caries:

- Also known as Tooth decay or cavities.
- This is the breakdown of teeth due to the acids made by bacteria.
- Caries is also associated with poor cleaning of the mouth.
- Receding gums resulting in exposure of the roots of the teeth is also dental caries.

Major causes of tooth decay:

- Sugary, sticky foods and beverages.
- The more the sugar consumed, the more the acid, gets produced leading to decay.
- Sugar combines with plaque to weaken the enamel leaving you vulnerable to tooth decay.
- Cavities are permanently damaged areas in the hard surface of teeth that develop into tiny openings or holes.
- Cavities start small and gradually become bigger when they're left untreated.
- Tatar, calculus, root canal.



Dyspepsia or Indigestion

Dyspepsia:

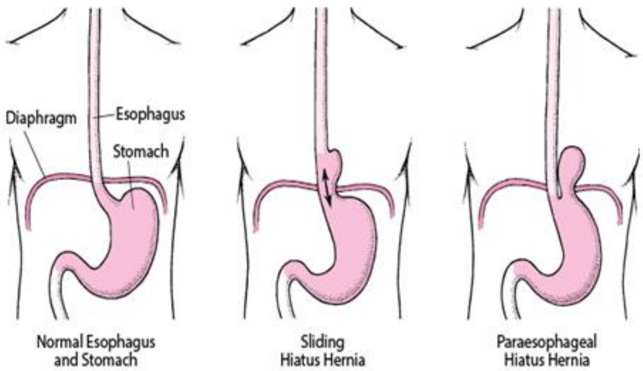
- It is characterized by incomplete of imperfect digestion.
- It is not a disease but sometimes symptoms of other disorders or diseases.

Symptoms:

- Abdominal discomfort
- Flatulance, Nausea, Vomiting

Causes:

- Excessive acidity in stomach
- Faulty function of stomach and intestine.
- Insufficient quantity of bile secretions.
- Eating too much and too rapidly.
- Eating fatty, greasy, or spicy foods.
- Drinking too much caffeine or alcohol.
- Consuming too much chocolate or soda.
- Emotional trauma.
- Gallstones.
- Gastritis or inflammation of the stomach.
- Hiatus hernia.



Food Poisoning

Illness from indigestion of food containing toxic substances is called food poisoning.

Symptoms:

- Diarrhea
- Vomiting
- Abdominal pain
- Occurs between 12-24 hours after eating contaminated food.

Causes:

- Eating improperly cooked (especially meat or eggs
- Drinking unpasteurized milk contaminated with *Salmonella* and *Campylobacte*r bacteria).

Preventions:

- The liquid that escapes during defrosting frozen meat contain *Salmonella.*
- The dishes and utensils while thawing must not be allowed to come in contact with any other food meat.

Anorexia Nervosa

- This term is employed to the loss of appetite due to the fear of becoming obese.
- Such a feeling is common in human females between the age of 12 to 21 years just on the onset of puberty.
- Fear is not diminished even when weight is dropped to dangerous level.

Symptoms:

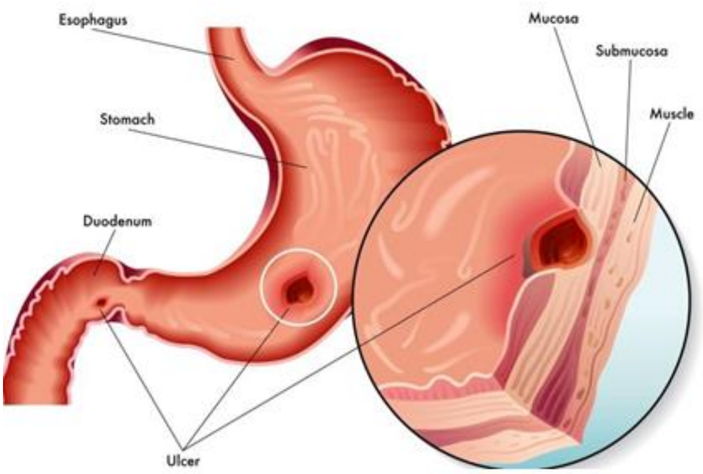
- Loss of appetite.
- Body weight drops to dangerous level.
- Young girls feel unable to cope with the changes of puberty and emerging sexuality psychologically.
- Anorexia girls have a strong feeling of becoming obese.

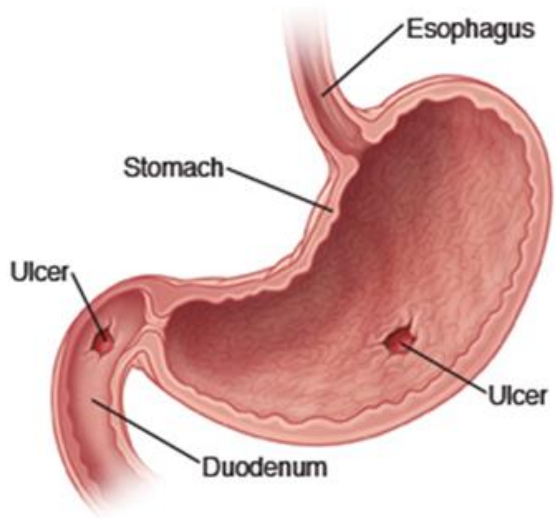
Treatment:

- Psychiatric therapy.
- Patients are fed intramuscularly or intravenously.
- Recovery is slow.

Gastric Ulcer

- Digestive tract is coated with a mucus layer that normally protects against acid.
- But if the amount of acid is increased or the amount of mucus is decreased, an ulcer develop
- Sore in digestive tract particularly in stomach and duodenum.
- This is formed when digestive enzymes begin to eat away the walls of GIT due to the breakdown of mucus layer lining the stomach.
- A hole in the lining of the stomach corroded by the acidic digestive juices which are secreted by the stomach cells.



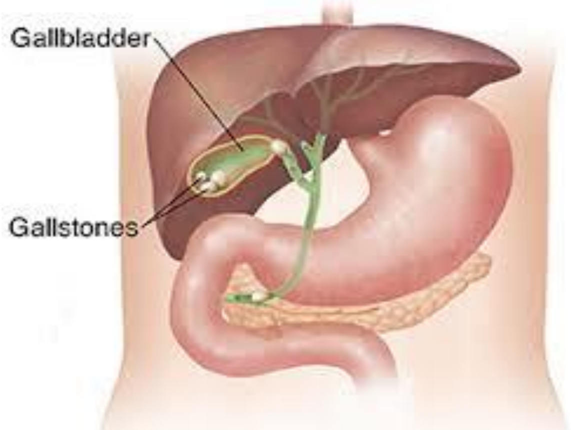


Causes:
- Use of spicy food
- *Helicobacter pylori* bacteria
- Alcoholic beverages
- Regular use of certain pain relievers
- Untreated stress

Symptoms:
- Point pain in affected area
- Burning sensation
- Nausea or vomiting
- Vomiting or vomiting blood — which may appear black.
- Dark blood in stools,
- Feeling faint
- Unexplained weight loss
- Fever and chills

Treatment:
- Avoid smoking
- Avoid eating spicy food
- Stop using alcohol
- Avoid coffee, tea and stress
- Surgery in extreme cases

Gallstones
- Gallstones are solid pebbles that form from bile cholesterol and bilirubin in the gallbladder.
- The gallbladder is a small pear-shaped saclike organ located under the liver.
- Liver in the present on the upper right part of the abdomen.



Symptoms:

- Gallstones, may be asymptomatic, even for years.
- A characteristic symptom of a gallstone attack is the presence of colicky pain in the upper-right side of the abdomen, often accompanied by nausea and vomiting.
- The pain steadily increases for approximately 30 minutes to several hours.
- Often, attacks occur after a particularly fatty meal and almost always happen at night, and after drinking.
- On the basis of composition of stones Gall stones can be classified as
    - a. Cholesterol stone
    - b. Pigment stone
    - c. Mixed stone

Cholesterol stones:

- Are composed of 70 to 80% cholesterol by weight.
- Between 35% and 90% of stones are cholesterol stones.

Pigment stones:

- These stones are small, often appearing black, and usually numerous.
- They are composed of bilirubin and $CaPO_4$ salts that are found in bile.
- They contain less than 20% of cholesterol.
- Between 2% and 30% of stones are bilirubin stones.
- Nutritional factors that may increase risk of gallstones include constipation; eating fewer meals per day; low intake of the nutrients folate, magnesium, calcium, and vitamin C; low fluid consumption

Mixed stones:

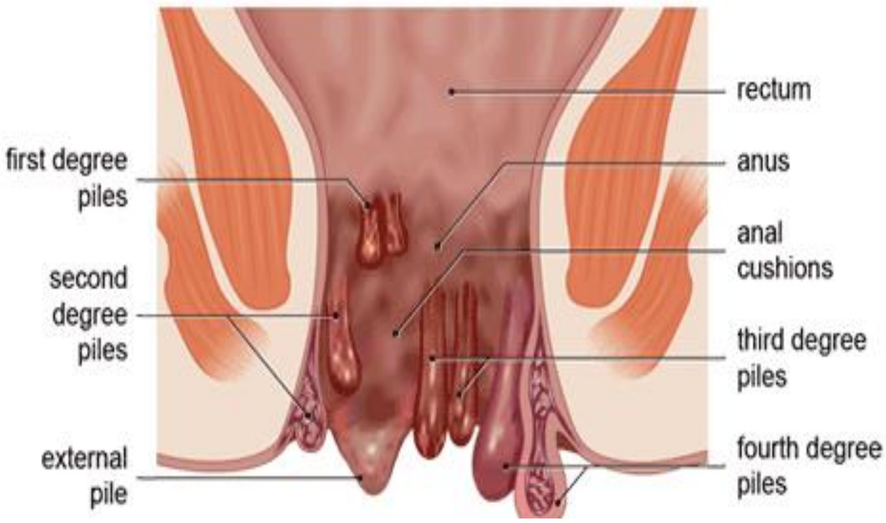
- Mixed stones contain 20–80% cholesterol.
- Other common constituents are calcium carbonate, palmitate phosphate, bilirubin and other bile pigments.
- Between 4% and 20% of stones are mixed.
- Nutritional factors that may increase risk of gallstones include:
- Constipation,
- Eating fewer meals per day,
- Low intake of the nutrients folate, magnesium, calcium, and vitamin C,
- Low fluid consumption.

Piles or Hemorrhoids

- Piles or Hemorrhoids are the masses of dilated tortuous veins in the anorectic mucosa.

Symptoms:

- The masses may sometimes start bleeding during bowl movements.
- The urge to defecate is depressed and it becomes difficult to expel the feces.
- Bleeding may aggravate when the patient suffers from constipation.



Treatment:

- Improvement of hygiene
- Food must contain roughage and laxatives.
- The patient is advised not to sit on hard seats.
- Surgery in severe cases.

Chapter#2
Homeostasis

- Homeostasis refers to the ability of an organism to maintain the internal environment (physical and chemical conditions) of the body within limits that allow it to survive.
- This includes many variables, which are kept within certain pre-set limits.
- These variables are:
    1. Fluid balance.
    2. Body temperature
    3. pH of extra cellular fluid
    4. Concentrations of Na^+, K^+ and Ca^{++} ions.
    5. Blood sugar level
- Each of these variables is controlled by one or more regulators or homeostatic mechanisms, which together maintain life.
- Equilibrium is kept maintained by many regulatory mechanisms, specially nervous system and endocrine system.

Concept of Thermoregulation

- Thermoregulation is the ability of an organism to keep its body temperature within certain limits, even when the surrounding temperature is very different.
- A thermo-conforming organism, by contrast, simply adopts the surrounding temperature as its own body temperature, thus avoiding the need for internal thermoregulation.
- The temperature of a living cell affects the rate of its metabolic processes.
- An animal can grow faster and respond to the environment more rapidly if its cells are kept warm.
- This ability to control the temperature of the body is called thermoregulation ("heat control") and involves the nervous, endocrine, respiratory, and circulatory systems in higher animals.
- In fact zoologists believe that the ability of some higher animals to maintain moderate body temperature is a major reason for their evolutionary success.

Concept of Osmoregulation

- It is defined as the maintenance of constant osmotic pressure in the fluids of an organism by the control of water and salt concentrations.
- It means osmoregulation governs water and salt balance, and excretion of metabolic wastes.
- In fishes, reptiles, birds, and mammals, the kidneys are the primary osmoregulatory structures.
- To understand osmoregulation, lets us first study the response of the cell in various external environments i.e. in different concentrations when the control system is not operating.
- In **hypertonic** solution cell shrinks due to the loss of water.
- In **hypotonic** solution the cell swells up and may even burst.
- To prevent these situations the cell's control system operates and osmoregulate itself to keep water and salts in balance in both plants and animals.

Osmoregulation in Animals:

- Based on osmoregulation the animals are divided into two groups:
    a. Osmoconformers
    b. Osmoregulators

- In first group of animals the osmotic concentration of the body fluids of the animals equals that of the medium.
- In other words, the osmotic concentration of the environment changes, so does that of the animal's body fluids.
- The osmoregulators maintain their body fluids at a different osmotic concentration from that of its surrounding environment.

Impact of Temperature on Animal Life

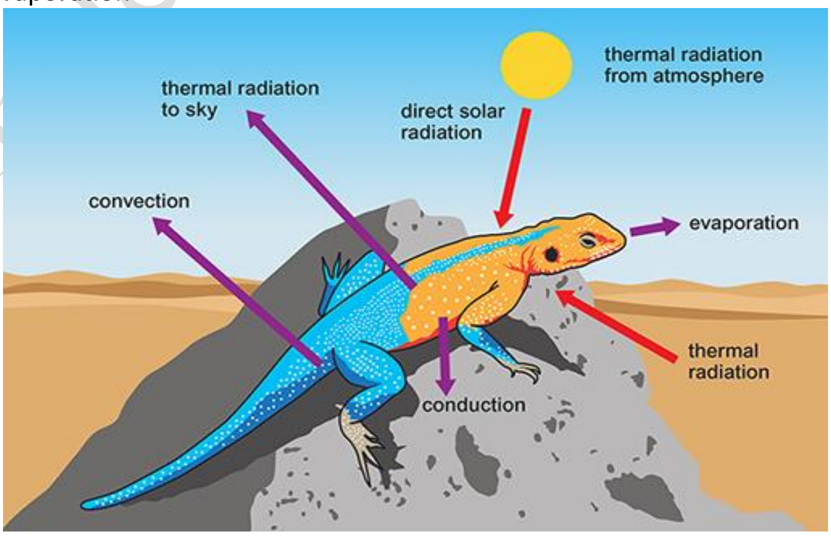
- As we know that metabolism is sensitive to changes in internal temperature.
- The rate of cellular respiration increases with temperature up to a point.
- When the temperature rises above the temperature optima the rate declines as the enzymes begin to denature.
- A digestive enzyme in a trout might function optimally at 10° C, whereas another enzyme in the human body catalyzes the same reaction functions best at 37° C.
- Higher temperatures cause the proteins in nucleic acids to denature, and
- Lower temperatures may cause membranes to change from a fluid to a solid state, which can interfere with many cellular processes, such as active transport pumps.
- It shows that enzyme evolution have frequently been enzymes with temperature optima that reflect an animal's habitat.
- Animals can guard against these damaging effects of temperature fluctuations by balancing heat gains and heat losses with their environment.

Heat Gains and Losses in Animals

- Animals produce heat as a by-product of metabolism.
- The total body temperature is a result of an interaction of these factors and can be expressed as:
- Body temperature = heat produced metabolically + heat gained from the environment - heat lost to the environment

Animals use four physical processes to exchange heat with the environment:

1. Conduction,
2. Convection
3. Radiation and
4. Evaporation



- **Conduction** is the direct transfer of (heat) from the environment to the body and from the body to the environment of an animal
- This transfer is always from an area of higher temperature to one of lower temperature.
- For example, when we sit on the cold ground, we lose heat, and when we sit on warm sand, we gain heat.
- **Convection** is the movement of air (or a liquid) over the surface of a body it contributes to heat loss if the air is cooler than the body or heat gain if the air is warmer than the body.
- On a cool day, our body loses heat by convection because our skin temperature is higher than the surrounding air temperature.

- **Radiation** is the emission of electromagnetic waves that the sun, or an object, produce.
- An object may be another animal.
- Radiation can transfer heat between objects that are not in direct contact with each other, as happens when an animal suns itself.

- **Evaporation** is the loss of heat from a surface of an animal.
- It is useful only to terrestrial animals.
- For example, humans and some other mammals (chimpanzees and horses) have sweat glands that actively move watery solutions through pores to the skin surface.
- When skin temperature is high, water at the surface absorbs enough thermal energy (heat) to break the hydrogen bonds holding the individual water molecules together, and they depart from the surface, carrying heat with them.

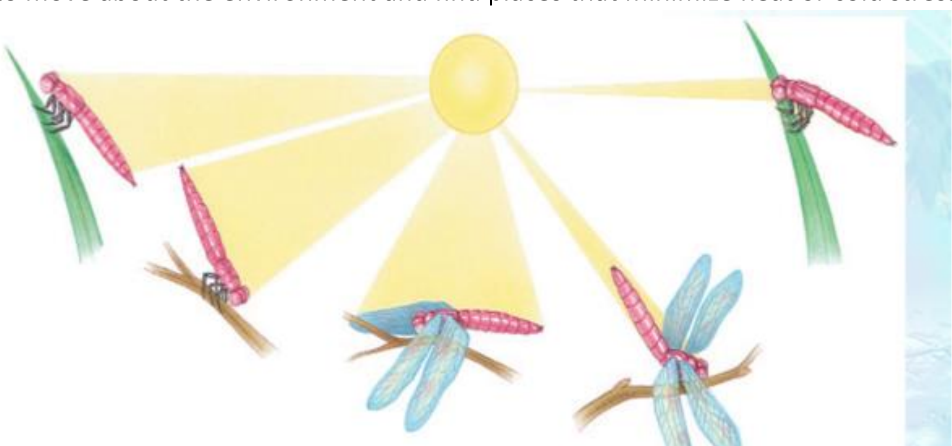
Some Solutions to Temperature Fluctuations in Animals

- There are three basic ways the animals cope with temperature fluctuations, either:
  1. They can occupy a place in the environment where the temperature remains constant and compatible with their physiological processes.
  2. Their physiological processes may have adapted to the range of temperatures in which the animals are capable of living, or
  3. They can generate and trap heat internally to maintain a constant body temperature, despite fluctuations in the temperature of the external environment.

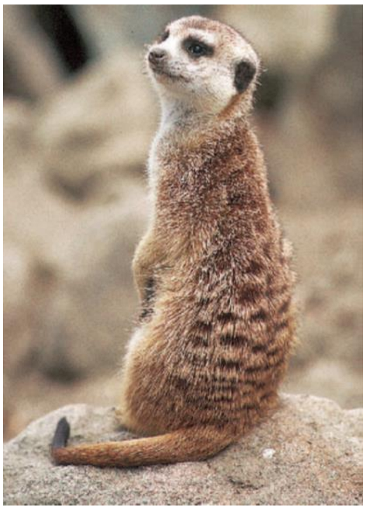
On this basis, animals can be categorized as:

1. Ectotherms
2. Endotherms

- Ectotherms derive most of their body heat from the environment rather than from their own metabolism.
- They have low rates of metabolism and are poorly insulated.
- In general, invertebrates, fishes, amphibians and reptiles are ectotherms, although a few insects, fishes and reptiles, can raise their internal temperature.
- Ectotherms tend to move about the environment and find places that minimize heat or cold stress to their bodies.



- A meerkat *(Suricata suricatta)* stands at attention, allowing the large surface area of its body to absorb radiation from the sun.



- **Endotherms** obtain their body heat from cellular processes.
- A constant source of internal heat allows them to maintain a nearly constant core temperature, despite the fluctuating environmental temperature.
- Examples are birds and mammals.
- Most endotherms have bodies insulated by feathers or fur and a relatively large amount of fat.
- This insulation enables them to retain heat more efficiently and to maintain a high core temperature.
- Endothermy allows animals to stabilize their core temperature so that biochemical processes and nervous system functions can proceed at steady, high levels.

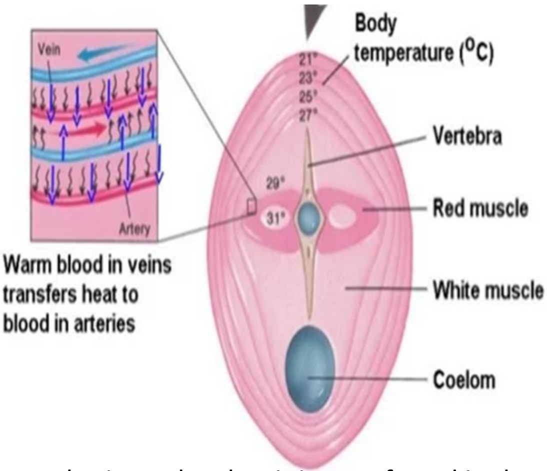
Ectothermy and Heterothermy

- Another way of categorizing animals is based on whether they maintain a constant or variable body temperature.
- Although most endotherms are homeotherms *(maintain a relatively constant body temperature),* and most ectotherms are heterotherms.
- There are many exceptions. Some endotherms vary their body temperatures seasonally (e.g., hibernation); others vary it on a daily basis.
- Examples:

  Hummingbirds and Shrews
- These animals can only maintain a high body temperature for a short period because they usually weigh less than 10 g and have a body mass so small that they cannot generate enough heat to compensate for the heat lost across their relatively large surface area.
- Hummingbirds must devote much of the day to locating and sipping nectar (a very high-calorie food source) as a constant energy source for metabolism.


Temperature Regulations in Fishes

- The temperature of the surrounding water determines the body temperature of most fishes.
- How Fishes live in extremely cold water?
    1. They have "antifreeze" materials in their blood in the form of Polyalcohols (e.g., sorbitol, glycerol) or water-soluble peptides and glycopeptides.Because these substances lower the freezing point of blood plasma and other body fluids.
    2. These fishes also have proteins or protein-sugar compounds that inhibit the growth of ice crystals that begin to form.
    3. These adaptations enable these fishes to stay flexible and swim freely in a super-cooled state (i.e., at a temperature below the normal freezing temperature of a surrounding water).
    4. These fishes have major blood vessels just under the skin.
- Branches deliver blood to the deeper, powerful, red swimming muscles, where smaller vessels are arranged in a countercurrent heat exchanger called the rete mirabile.



- The heat generated by red muscles is not lost but it is transferred in the rete mirabile from venous warm blood to cold arterial blood.
- Some active fishes maintain a core temperature significantly above the temperature of the water.
- For example: bluefin tuna and the great white shark.
- This arrangement of blood vessels enhances vigorous activity by keeping the swimming muscles several degrees warmer than the tissue near the surface of the fish.
- This system has been adaptive for these fishes.

Temperature Regulation in Amphibians

- Surrounding medium of most the amphibians is air as well as water.
- They face marked daily and seasonal temperature changes.
- Most of these animals derive heat from their environment.
- Their body temperatures vary with external temperatures, i.e. they are ectothems.
- Most amphibians have difficulty in controlling body temperature because they produce little heat metabolically and rapidly lose most of it from their body surfaces.
- However, behavioral adaptations enable them to maintain their body temp. within a homeostatic range most of the time.
- Amphibians have an additional thermoregulatory problem because they must exchange oxygen and carbon dioxide across their skin surface, and this moisture layer acts as a natural evaporative cooling system.
- This problem of heat loss through evaporation limits the habitats and activities of amphibians to warm, moist areas.
- Some amphibians, such as bullfrogs, can vary the amount of mucus they secrete from their body surface.
- This is as physiological response that helps regulate evaporative cooling.

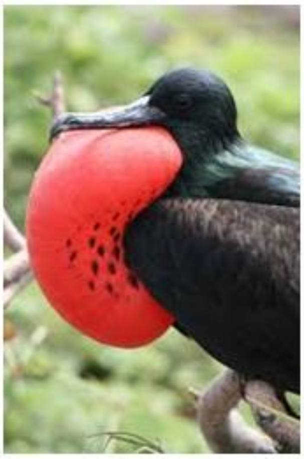

Temperature Regulations in Reptiles

- Reptiles have dry rather than moist skin, which reduces the loss of body heat through evaporative cooling of the skin.
- They also have an expandable rib cage, which allows for more powerful and efficient ventilation
- Reptiles have a low metabolic rate and warm themselves by behavioral adaptations.
- In addition, some of the more sophisticated regulatory mechanisms found in mammals are first found in reptiles.
- For example, diving reptiles conserve body heat by routing blood through circulatory shunts (an alternative path for the passage of the blood) into the center of the body. (e.g., sea turtles, sea snakes)
- These animals can also increase heat production in response to the hormones thyroxine and epinephrine.
- In addition, tortoises and land turtles can cool themselves through salivating and frothing at the mouth, urinating on the back legs, moistening the eyes, and panting.




Temperature Regulation in Aves or Birds

- Birds like mammals are the most active and behaviorally complex vertebrates.
- They can live in habitats all over the earth because they are homeothermic endotherms.
- They can maintain body temperatures between 35 and 42° C with metabolic heat.
- Various cooling mechanisms prevent excessive warming in birds. Because they have no sweat glands, birds pant to lose heat through evaporative cooling.
- Some species have a highly vascularized pouch (gular pouch) in their throat that they can flutter to increase evaporation from the respiratory system.



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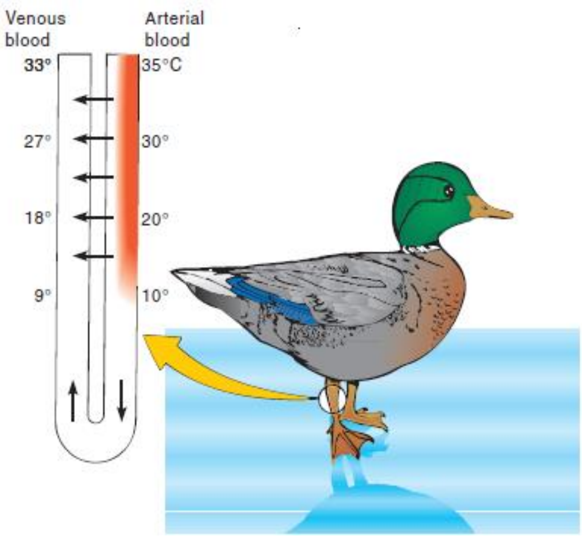
- Some birds possess mechanisms for preventing heat loss.
- Feathers are excellent insulators for the body, especially downy feathers that trap a layer of air next to the body to reduce heat loss from the skin.

- Aquatic species, which lose heat from their legs and feet, have peripheral countercurrent heat exchange vessels called a rete mirabile in their legs to reduce heat loss.
- The arteries carry warm blood down the legs to warm the cooler blood in the veins, so that the heat is carried back to the body rather than lost through the feet that are in contact with a cold surface.



Temperature Regulation in Mammals

- Mammals like birds are also active and behaviorally complex vertebrates.
- They can live in habitats all over the earth because they are homeothermic endotherms.
- They can maintain body temperatures between 35 and 42° C with metabolic heat.
- Mammals that live in cold regions, such as the arctic fox and barren-ground caribou, also have these exchange vessels in their extremities (e.g., legs, tails, ears, and nose).


- Animals in hot climates, such as jackrabbits, have mechanisms (e.g., large ears) to get rid of excess heat from the body surface.

- Marine animals, such as seals and whales, thick pelts and a thick layer of insulating fat called blubber just under the skin help to maintain a body temperature around 36 to 38°C
- In the tail and flippers, which have no blubber, a countercurrent system of arteries and veins helps minimize heat loss.

- Birds and mammals also use behavioral mechanisms to cope with external temperature changes.
- Like ectotherms, they sun themselves or seek shade as the temperature fluctuates.
- Many animals cluster to keep warm; others share burrows for protection from temperature extremes.
- Migration to warm climates and hibernation enable many different birds and mammals to survive the harsh winter months.

- Others, such as the desert camel, have a multitude of evolutionary adaptations for surviving in some of the hottest and driest climates on earth.
- Camels are well adapted for survival in the desert. Their adaptations include
- Large, flat feet - to spread their weight on the sand.
- thick fur on the top of the body for shade, and
- Thin fur elsewhere to allow easy heat loss.
- It excrete very little of urine and dry dung. It has hump which stores fat.

Heat Production in Birds

- In birds, heat generation can warm the body as it dissipates through the tissues and organs.
- Birds like mammals can generate heat by muscle contraction (thermogenesis).
- Every time a muscle cell contracts, the actin and myosin filaments sliding over each other and the hydrolysis of ATP molecules generate heat.
- Both voluntary muscular work (e.g., running, flying, jumping) and involuntary muscular work (e.g., shivering) generate heat.
- Heat generation by shivering is called **shivering thermogenesis.**
- When birds's body cools, the thyroid gland releases the hormone thyroxine.
- Thyroxine increases the permeability of many cells to sodium (Na) ions, which leak into the cells.
- The ATPase pump quickly pumps these ions out.
- In this process, ATP is hydrolyzed, releasing heat energy.
- This hormonal triggering of heat production is called **non-shivering thermogenesis.**
- The basal metabolic rate (BMR) of birds and mammals is high and also produces heat involuntarily but useful by-product.

Heat Production in Mammals

- In endotherms (birds and mammals), heat generation can warm the body as it dissipates through the tissues and organs.
- Mammals like birds can generate heat by muscle contraction (thermogenesis).
- Every time when a muscle cell contracts, the actin and myosin filaments sliding over each other the hydrolysis of ATP molecules generate heat.
- Mammals that live in cold climates, and hibernate have a specialized type of fat called Brown fat found in newborn babies.
- The brown color of this fat comes from the large number of mitochondria with their iron-containing cytochromes.
- Deposits of brown fat are beneath the ribs and in the shoulders.
- A large amount of heat is produced when brown fat cells oxidize fatty acids.
- Blood flowing past brown fat is heated and contributes to warming the body.
- The BMR of mammals is high and also produces heat involuntarily but useful by-product.
- During winter, various endotherms (e.g., bats, woodchucks, ground squirrels) go into hibernation .
- During hibernation the metabolic rate slows, as do the heart and breathing rates.
- Mammals prepare for hibernation by building up fat reserves and growing long winter pelts.


- Hibernation is a state of inactivity and metabolic depression in endotherms.
- Hibernation is a seasonal heterothermy characterized by low body-temperature, slow breathing and heart-rate, and low metabolic rate.
- It occurs most commonly during winter months.
- Aestivation is a state of animal dormancy, similar to hibernation, although taking place in the summer rather than the winter.
- Aestivation is characterized by inactivity and a lowered metabolic rate, that is entered in response to high temperatures and arid conditions.
- Aestivation takes place during times of heat and dryness, the hot dry season, which are often the summer months.

Hibernation and Aestivation

- Hibernation is a state of seasonal inactivity in animals characterized by low body-temperature, slow breathing and heart-rate, and low metabolic rate.
- It commonly occurs during winter months.
- Hibernation functions to conserve energy when sufficient food is unavailable.
- To achieve this energy saving, an endothermic animal decreases its metabolic rate and thereby its body temperature.
- Hibernation may last days, weeks, or months - depending on:
    a. the species,
    b. ambient temperature,
    c. time of year, and
    d. The individual's body-condition.
- Before entering hibernation, animals need to store enough energy to last through the duration of their dormant period, possibly as long as an entire winter.
- Larger species become hyperphagic, eating a large amount of food and storing the energy in fat deposits.
- Some species of mammals hibernate while pregnant.
- Babies are born either during the hibernation of the mother or shortly afterwards.
- For example, female polar-bears go into hibernation during the cold winter months in order to give birth to their offspring.
- Aestivation is a state of animal dormancy, similar to hibernation, although taking place in the summer rather than the winter.
- Aestivation is characterized by inactivity and a lower metabolic rate, in response to high temperatures and arid conditions.
- It takes place during times of heat and dryness, the hot dry season, which are often the summer months.
- The "baseline" metabolic rate of an animal is measured as the basal metabolic rate (BMR) for an endotherm or as the standard metabolic rate (SMR) for an ectotherm.
- Torpor is a state of decreased physiological activity in an animal, usually by a reduced body temperature and metabolic rate.
- Animals that undergo daily torpor include birds (even tiny hummingbirds, and some mammals, including many marsupial species, rodent species (such as mice), and bats.
- Some animals, such as badgers, bears, opossums, raccoons, and skunks, enter a state of prolonged sleep in the winter. Since their body temperature remains near normal, this is not true hibernation.

Osmoregulation and Excretion
(Control of Water and Solutes)

Osmoregulation

- Osmoregulation is the process by which an organism regulates the water balance in its body to maintain homeostasis.
- Osmoregulation is necessary for animals in all habitats.
- If the osmotic concentration of the body fluids of an animal equals that of the medium *(the animal's environment)*, the animal is an osmoconformer.
- This type of osmoregulation is not efficient and has limited the distribution of those animals using it.
- Osmoconformers are marine organisms that maintain an internal environment which is isotonic to their external environment.
- This means that the osmotic pressure of the organism's cells is equal to the osmotic pressure of their surrounding environment.
- Examples: hagfish skates and sharks.

Osmoregulator.

- In contrast, an animal that maintains its body fluids at a different osmotic concentration from that of its surrounding environment is an omoregulator.
- Examples. Some fish have evolved osmoregulatory mechanisms to survive in all kinds of aquatic environments.
- Land animals have a higher concentration of water in their fluids than in the surrounding air.
- They tend to lose water to the air through evaporation and may use considerable amounts of water to dispose of wastes.
- The form and function of organs or systems associated with osmoregulation are related both to environmental conditions (saltwater, freshwater, terrestrial) and to body size (especially the surface-to-volume ratio).

Excretion in Animals

Excretion

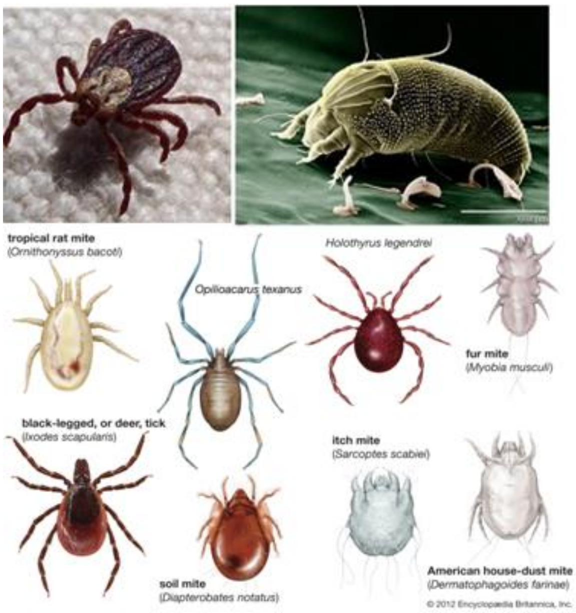
- Excretion can be defined broadly as the elimination of metabolic waste products from an animal's body.
- These products include CO_2 and H_2O (which cellular respiration produces) and Nitrogen products.
- Excess nitrogen is produced as:
    a. Ammonia from deamination of amino acids.
    b. Urea and uric acid and solutes (various ions).
    c. Some of Nitrogen is excreted as ceatinine and creatine .
- Excretion of nitrogenous wastes is usually associated with the regulation/supply of water and solute (ionic) balance by a physiological process called osmoregulation.
- The nature of excretory product is determined mainly by the availability of water to the organism i.e. its habitat.
- This correlation is summarized as:

Ammonia	*aquatic*
Urea	*aquatic/terrestrial*
Uric acid	*terrestrial*

- Ammonia is extremely toxic and must be eliminated rapidly and safely. This applies only to freshwater organisms.
- Urea is produced by animals that have moderate water supply. Such as amphibians and human.
- Uric acid and its salts are ideal products for terrestrial organisms, for example insects and birds.

Invertebrate Excretory Systems

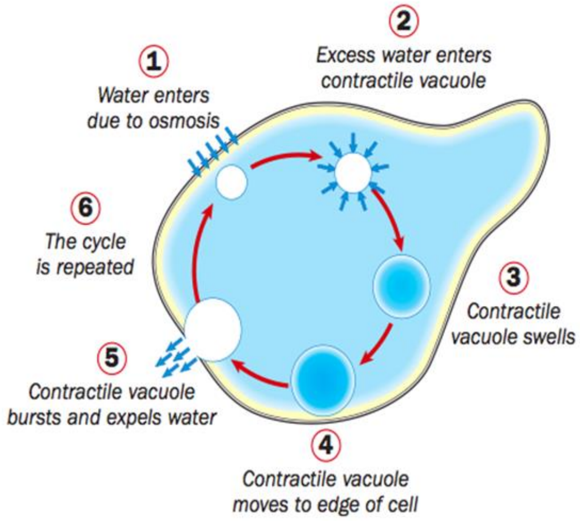
- Aquatic invertebrates occur in a wide range of media, from freshwater to markedly hypersaline water (e.g., salt lakes).
- Generally, marine invertebrates have about the same osmotic concentration as seawater (i.e., they are osmoconformers).
- It means they need not to osmoregulate.
- Most water and ions are gained:
    a. across the integument,
    b. via gills,
    c. by drinking,
    d. and in food.
- Ions and wastes are mostly lost by diffusion via the integument, gills, or urine.
- Freshwater invertebrates are strong osmoregulators.
- Any water gain is usually eliminated as urine.
- A number of invertebrate taxa have more or less successfully invaded terrestrial habitats.
- The most successful terrestrial invertebrates are the Arthropods, particularly the insects, spiders, scorpions, ticks, mites, centipedes, and millipedes.



- Overall, the water and ion balance of terrestrial invertebrates is quite different from that of aquatic animals because terrestrial invertebrates face limited water supplies and water loss by evaporation from their integument.
- Some of the invertebrate excretory mechanisms and systems are now discussed.
- Mites can feed on plants and animals while ticks strictly live on animal hosts.
- Both ticks and mites transmit disease to their hosts.
- Mites transmit two major diseases including scrub typhus, and scabies.

Contractile Vacuoles

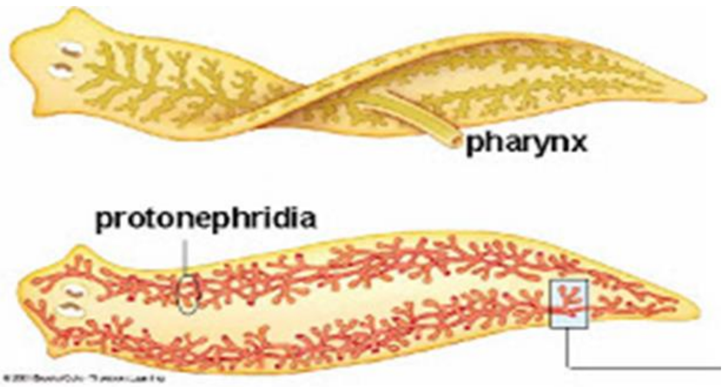
- The contractile vacuole is a specialized type of vacuole that regulates the quantity of water inside a cell.
- A contractile vacuole is a sub-cellular structure involved in osmoregulation.
- The contractile vacuole, as its name suggests, expels water out of the cell by contracting.
- In freshwater environments, the concentration of solutes is hypotonic, higher inside than outside the cell.
- Many freshwater species (protozoa, sponges), have contractile vacuoles that pump out excess water.



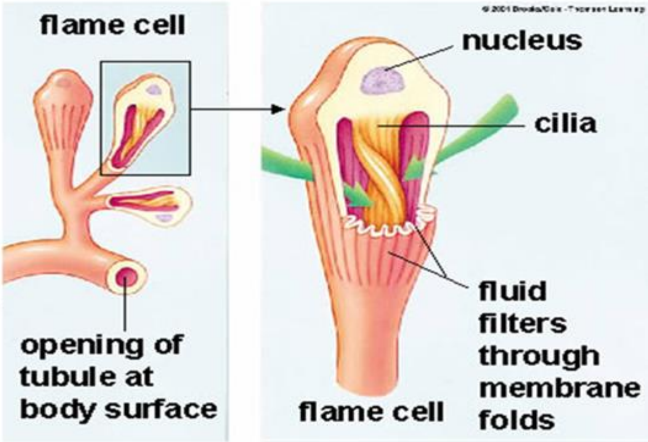
- Contractile vacuoles are energy-requiring devices that expel excess water from individual cells exposed to hypo-osmotic environments
- Some protists and marine invertebrates (e.g., protozoa, cnidarians, echinoderms, sponges) do not have specialized excretory structures because wastes simply diffuse into the surrounding isoosmotic water.

Excretory System in Turbellarian (Protonephridia)

- A few groups of metazoan invertebrates possess structures, that serve for excretion, osmoregulation, or both, ther are the nephridia.
- Among nephridia the simplest are the protonephridia or flame-cell systems.
- These are found in flatworms, rotifers, some annelids, and larval molluscs.
- The protonephridial excretory system is composed of a network of excretory canals that open to the outside of the body through excretory pores.
- Bulblike flame cells are located along the excretory canals.



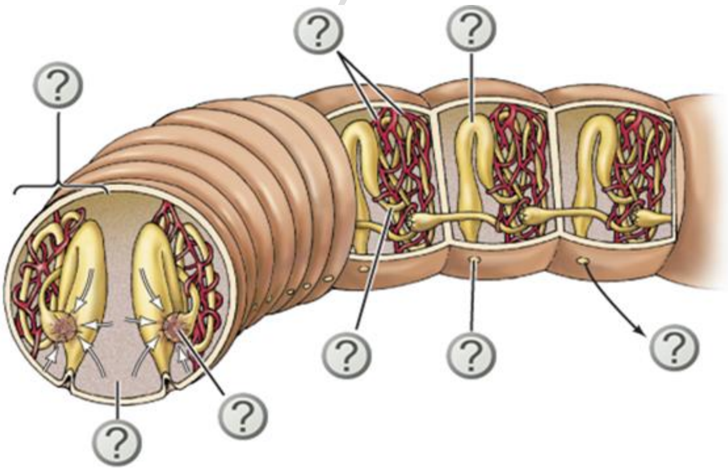
- A flame cell is a specialized excretory cell found in the simplest freshwater invertebrates, including flatworms, rotifers and nemerteans (ribbon worms); these are the simplest animals to have such an excretory system.



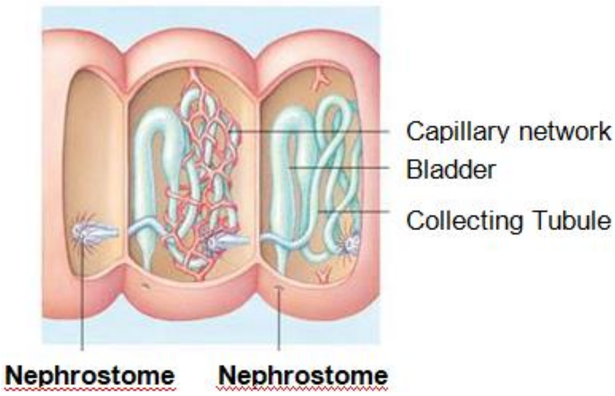
- Chiefly Nitrogenous waste simply diffuses across the body surface into the surrounding water.

Excretory System in Annelida

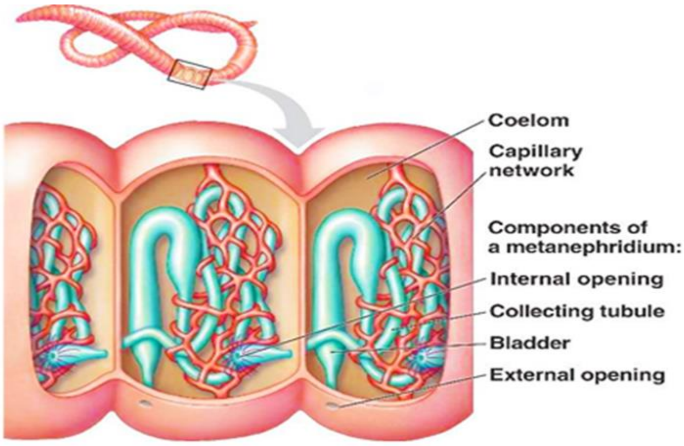
- A more advanced type of excretory structure among invertebrates is the metanephridium.
- Metanephridium is a type of excretory gland found in invertebrates such as annelids, arthropod and mollusca.
- Unlike protonephridia , the metanephridia open internally to the body fluids and are multicellular.
- The metanephridium opens by a ciliated nephrostome into the cavity of one segment, and the next segment contains the nephridiopore.
- Most segments contain two metanephridia.
- Most annelids (such as the common earthworm) and a variety of other invertebrates have a metanephridial excretory system. Recall that the earthworm's body is divided into segments and that each segment has a pair of metanephridia.



- The main tubular portion of the metanephridium is coiled and is surrounded by a capillary network.
- Waste can be stored in a bladder before expelling outside.



- Each metanephridium begins with a ciliated funnel, the nephrostome, that opens from the body cavity of a segment into a coiled tubule.
- As beating cilia move the fluid through the tubule, a network of capillaries surrounding the tubule reabsorbs and carries away ions.

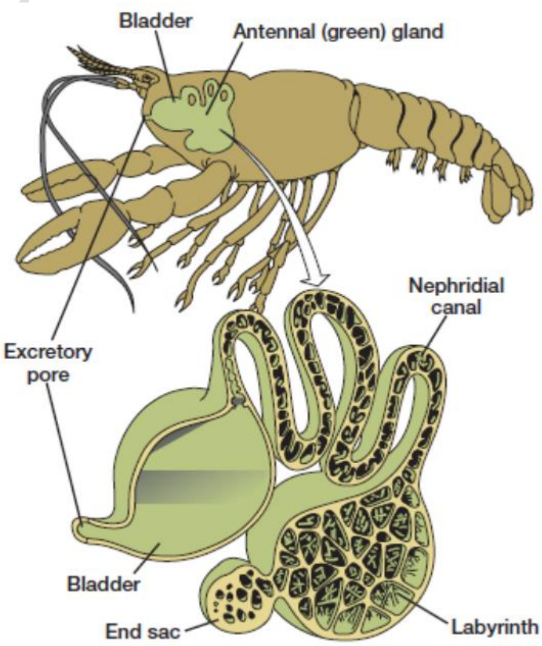


metanephridia

- Each tubule leads to an enlarged bladder that empties to the outside of the body through an opening called the nephridiopore.
- The excretory system of molluscs includes protonephridia in larval stages and metanephridia in adults.

Excretory System in Crutacean

- Crustaceans that have gills, nitrogenous wastes are removed by simple diffusion across the gills. Most crustaceans release ammonia, although they also produce some urea and uric acid as waste products.
- The excretory organs of freshwater species are more involved with the reabsorption of ions and elimination of water than with the discharge of nitrogenous wastes.
- The excretory organs in some crustaceans (crayfish, crabs) are antennal glands or green glands because of their location near the antenna and their green color.
- The antennal gland, lies in front of and on both sides of the esophagus.
- The gland is divided into :
  - **An End Sac,** where fluid collects by filtration.
  - **A Labyrinth**, the walls of which are greatly folded and is glandular and an important site for reabsorption.

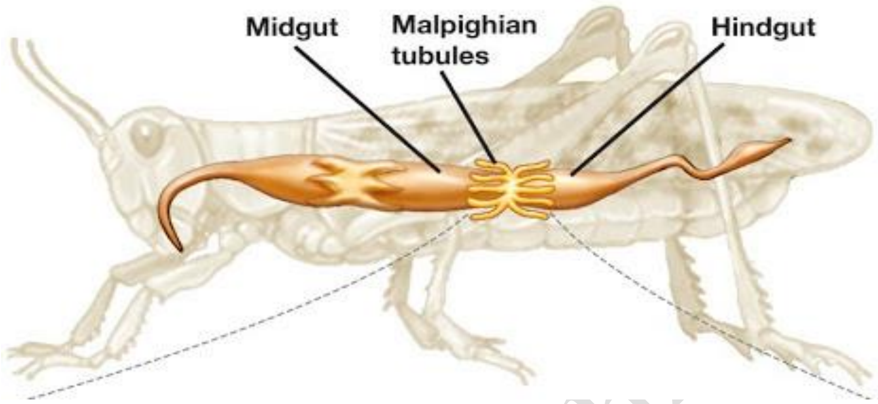


- **Nephridial Canal** a canal that leads into bladder.
- **Bladder** a short duct leads to an excretory pore.

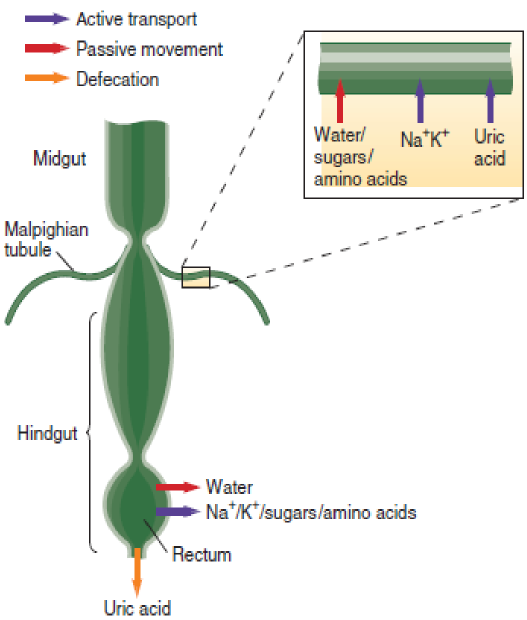
- The fluid filters into the antennal gland from the hemocoel.
- The heart exerts pressure on Hemolymph which is the main driving force for filtration.
- Marine crustaceans have a short nephridial canal and produce urine that is isoosmotic to their hemolymph.
- The nephridial canal is longer in freshwater crustaceans, which allows more surface area for ion transport.

Excretory System in Insects

- Insects have an excretory system made up of the gut and Malpighian tubules attached to the gut.
- Excretion involves the active transport of potassium ions into the tubules from the surrounding hemolymph and the osmotic movement of water that follows.



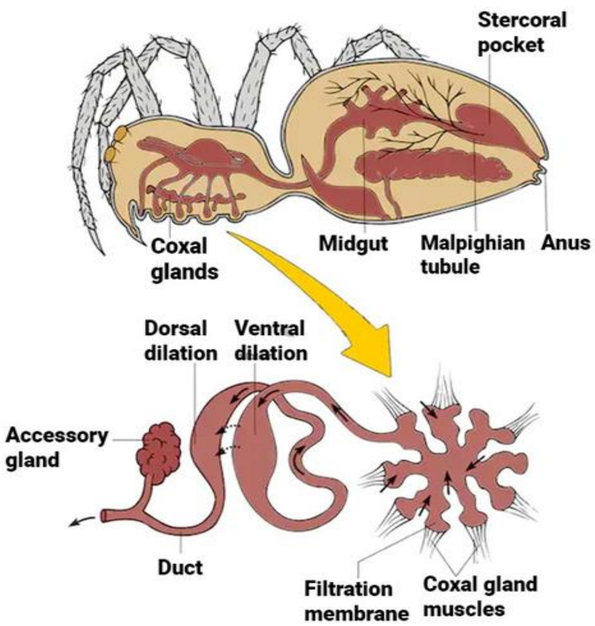
- Nitrogenous waste (uric acid) also enters the tubules.
- As fluid moves through the Malpighian tubules, some of the water and certain ions are recovered.
- All of the uric acid passes into the gut and out of the body.



- Malpighian tubules remove nitrogenous wastes (uric acid) from the hemocoel.
- Various ions are actively transported across the outer membrane of the tubule.
- Water follows these ions into the tubule and carries amino acids, sugars, and some nitrogenous wastes along passively.
- Some water, ions, and organic compounds are reabsorbed in the basal portion of the Malpighian tubules and the hindgut.
- The rest are reabsorbed in the rectum.

Excretory System in Archnids

- Among arachnids (spiders, scorpions, ticks, mites) Coxal glands are glands for collecting and excreting urine.
- They are present on one to several pairs of appendages near the proximal joint (coxa) of the leg.
- The glands are highly convoluted tubule sections, doubling back of straight tubule sections, and expansion of the terminal end into a bladder.
- Wastes are collected from the surrounding hemolymph of the hemocoel and discharged through pores



- The coxal gland is thought to be homologous with the antennal gland of crustaceans.
- Recent evidence suggests that the coxal glands may also function in the release of pheromones.

Vertebrate Excretory Systems

- Vertebrates face the same problems as invertebrates in controlling water and ion balance.
- Generally, water losses are balanced precisely by water gains.

Water Gain:

- Vertebrates gain water from liquids and solid foods through:
- the small,
- large intestines, and
- By metabolic reactions that yield water as an end product.

Water Loss:

- They lose water by evaporation:
- from respiratory surfaces,
- from the integument,
- sweating or panting,
- elimination in feces and
- Excretion by the urinary system.

Solute Absorption:

- Vertebrates take in solutes by absorption of minerals from:
- the small and large intestines,
- through the integument
- gills,
- from secretions of various glands and
- By metabolism (e.g., the waste products of catabolic reactions).

Solute Elimination:

- Vertebrates lose solutes through:
- sweat,
- feces,
- urine, and
- Gill secretions as metabolic wastes.
- The major metabolic wastes that are eliminated as ammonia, urea, or uric acid.

- Different vertebrates face different water and solute problems and solve them in different ways.
- How vertebrates maintain homeostatic solvent/solute concentrations in their body fluids will be discussed next.
- The excretion of certain metabolic waste products is also coupled with osmotic balance and will be discussed with the urinary system.
- Solute losses also must be balanced by solute gains.

AVERAGE WATER GAIN AND LOSS IN HUMAN AND KANGROO RAT

VERTEBRATE	WATER GAIN (ml)		WATER LOSS (ml)	
Human	Ingested in solid food	1200	Feces	100
	Ingested in liquids	1000	Urine	1500
	Metabolically produced	350	Skin and lungs	950
	Total	2550		2550
Kangroo rat	Ingested in solid food	6	Feces	3
	Ingested in liquids	0	Urine	13
	Metabolically produced	54	Skin and lungs	44
	Total	60		60

Osmoregulation in Vertebrates

- A variety of mechanisms have evolved in vertebrates to cope with their osmoregulatory problems, and most of them are adaptations of the urinary system.
- Vertebrates have a closed circulatory system containing blood that is under pressure.
- This pressure forces blood through a membrane filter in a kidney, where the following three key functions take place:
  - Filtration
  - Reabsorption
  - Secretion

1. **Filtration**

- In this process blood passes through a filter that retains blood cells, proteins, and other large solutes but let's small molecules, ions, and urea pass through.

2. **Reabsorption**

- In reabsorption selective ions and molecules are taken back into the bloodstream from the filtrate.

3. **Secretion**

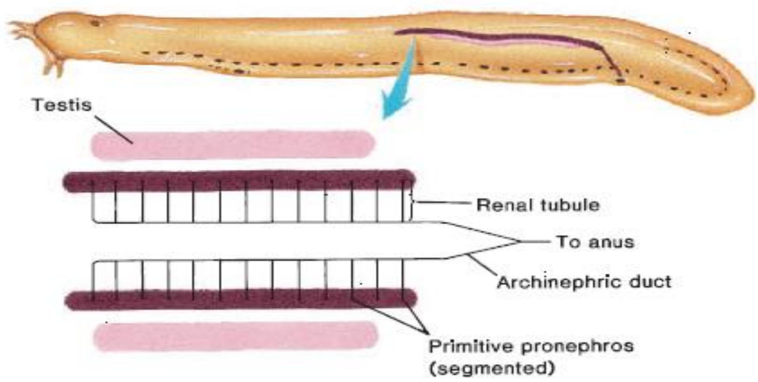
- In this process select ions and end products of metabolism (e.g., K, H, NH3) that are in the blood are added to the filtrate for removal from the body.

Vertebrate Kidney Variations

- Vertebrates have two kidneys that are in the back of the abdominal cavity, on either side of the aorta.
- Each kidney has a coat of connective tissue called the renal capsule.
- The inner portion of the kidney is called the medulla; the region between the capsule and the medulla is the cortex.
- The structure and function of vertebrate kidneys differ, depending on the vertebrate groups and the developmental stage.
- Overall, there are three kinds of vertebrate kidneys:
    1. Pronephros,
    2. Mesonephros, and
    3. Metanephros.

1. The Pronephros:

- Appears only briefly in many vertebrate embryos, and not at all in mammalian embryos.
- In some vertebrates, the pronephros is the first osmoregulatory and excretory organ of the embryo as in tadpoles and other amphibian larvae.
- In vertebrates such as in hagfishes, pronephros remains as the functioning kidney.
- The primitive pronephric kidney is found in adult hagfishes and in the embryos of fishes and amphibians.

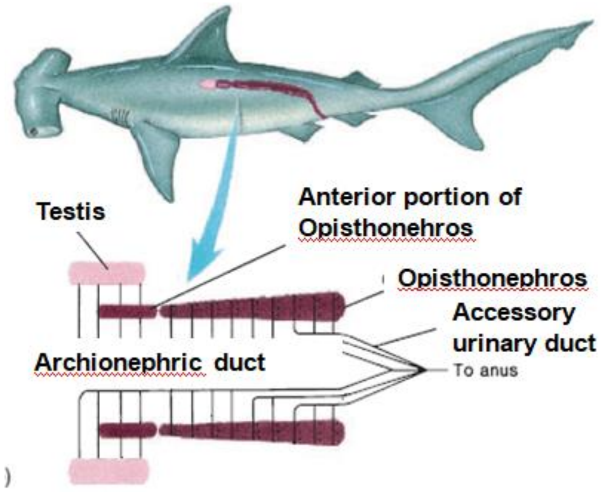


- In the anterior half of the body the renal tubules occur in segments that lead from the body of the pronephros to the archinephric duct.
- Notice that the testes are separate from the kidneys.

2. The Mesonephros

- It is one of three excretory organs that develop in vertebrates.
- It is a paired organ consisting of a set of nephrons having capsules that filter blood from the glomerulus and tubules whose cells reabsorb water and nutrients and secrete nitrogenous wastes.

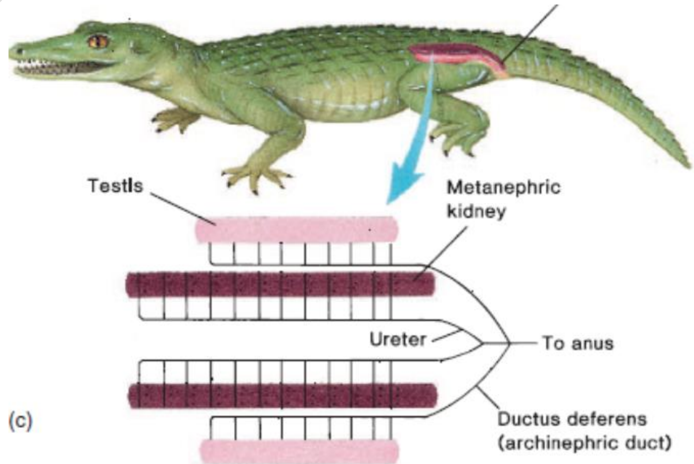
- It serves as the main excretory organ of aquatic vertebrates and as a temporary kidney in reptiles, birds, and mammals.
- During embryonic development of amniotes, or during metamorphosis in amphibians, the mesonephros replaces the pronephros.
- The mesonephros is the functional embryonic kidney of many vertebrates and also adult fishes and amphibians.
- It is structurally similar to the nonsegmented opisthonephric (advanced mesonephric) kidney of most nonamniote vertebrates, such as sharks.



- The anterior portion of the opisthonephros functions in blood cell formation and secretion of sex hormones.
- Notice that the testes occupy the position of the anterior opisthonephros, and the archinephric duct carries both sperm and urine.
- Glomeruli are absent in some marine fish; urine then forms solely in the tubules.
- The tubules empty into a long tube, the Wolffian duct, a remnant of the pronephros.
- In more advanced vertebrates the mesonephros develops in the embryo but is replaced after the 10th week by the metanephros as in humans.

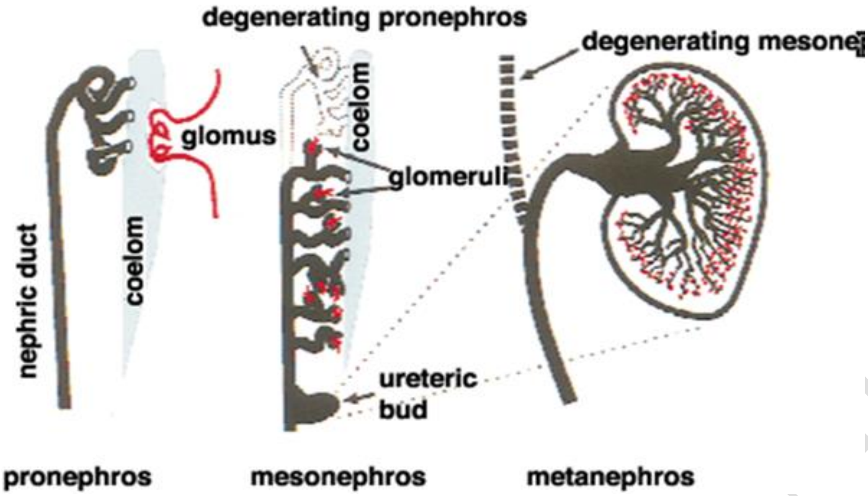
3. The Metanephros

- Member of the final and most caudal pair of vertebrate renal organs that functions as a permanent adult kidney is in reptiles, birds, and mammals.
- Not present at all in lower forms.



- The physiological differences between these kidney types are primarily related to the number of blood-filtering units.
- The pronephric kidney is formed in the anterior portion of the body cavity and contains fewer blood-filtering units than either the mesonephric or metanephric kidneys.

- The larger number of filtering units in the latter has allowed vertebrates to face the rigorous osmoregulatory and excretory demands of freshwater and terrestrial environments.
- What follows is a presentation of how a few vertebrates maintain their water and solute concentrations in different habitats—in the seas, in freshwater, and on land.

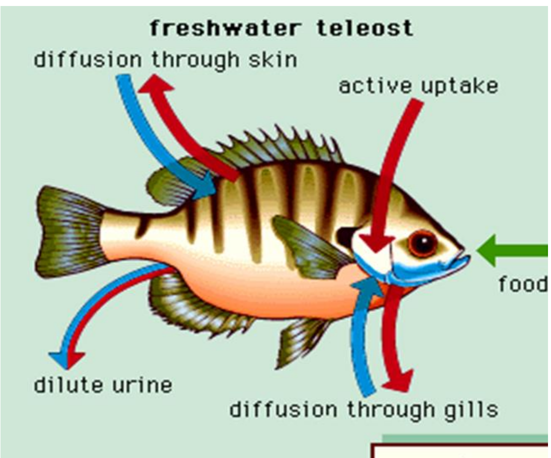


Excretion in Sharks

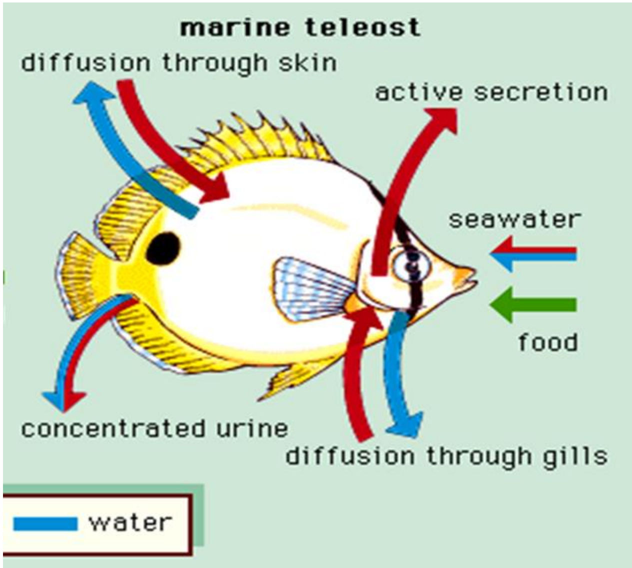
- Sharks and their relatives (skates and rays) have mesonephric kidneys and have solved their osmotic problem in ways different from the bony fishes.
- Instead of actively pumping ions out of their bodies through the kidneys, they have a rectal gland that secretes a highly concentrated salt (NaCl) solution.
- To reduce water loss, they use two organic molecules—urea and trimethylamine oxide (TMO)—in their body fluids to raise the osmotic pressure to a level equal to or higher than that of the seawater.
- Urea denatures proteins and inhibits enzymes, where asTMO stabilizes proteins and activates enzymes.
- Together in the proper ratio, they counteract each other, raise the osmotic pressure, and do not interfere with enzymes or proteins.
- This reciprocity is termed the counteracting osmolyte strategy.

Excretion in Teleost Fishes

- Most teleost fishes have mesonephric kidneys.
- Since the body fluids of freshwater fishes are hyper-osmotic relative to freshwater, water tends to enter the fishes, causing excessive hydration or bloating.
- They absorb salts and ions by active transport across their gills.
- They also excrete a large volume of water as dilute urine.
- Freshwater fishes have enlarged glomeruli and short tubule systems.

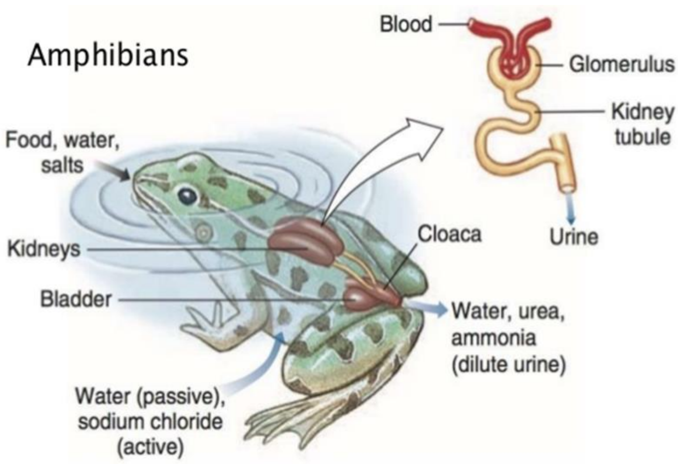


- They filter large quantities of water from the blood and tubules reabsorb some ions from the filtrate.
- Freshwater fishes produce a hypo-osmotic urine.
- Marine fishes face a different problem of water balance—their body fluids are hypoosmotic with respect to seawater and water tends to leave their bodies, resulting in dehydration.
- Marine fishes conserve water by reducing the size of the glomerulus of the nephron, and thus reducing the quantity of water and ions filtered from the blood.
- Ions can be secreted from the blood into the kidney tubules.
- Marine fishes can produce urine that is iso-osmotic with the blood.
- To compensate, marine fishes drink large quantities of water, and they secrete Na, Cl, and K ions through secretory cells in their gills.
- Channels in plasma membranes of their kidneys actively transport the multivalent ions that are abundant in seawater (e.g., Ca2, Mg2, SO4 and PO4) out of the extracellular fluid and into the nephron tubes.
- The ions are then excreted in concentrated urine.



Excretion in Amphibians

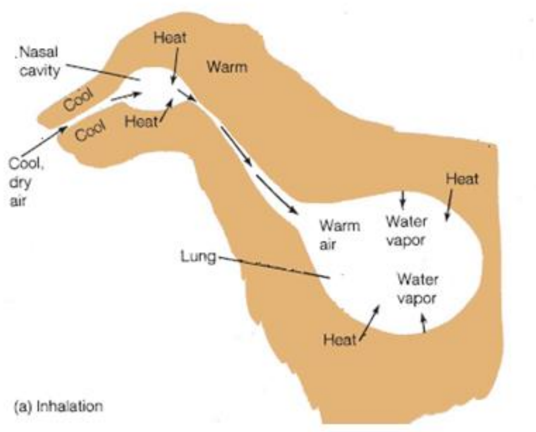
- The amphibian kidney is identical to that of freshwater fishes.
- This is not surprising, because amphibians spend a large portion of their time in freshwater, and when on land, they tend to seek out moist places.
- Amphibians take up water and ions in their food and drink, through the skin that is in contact with moist substrates, and through the urinary bladder.
- This uptake counteracts what is lost through evaporation and prevents osmotic imbalance.
- The urinary bladder of a frog, toad, or salamander is an important water and ion reservoir.
- For example, when the environment becomes dry, the bladder enlarges for storing more urine.



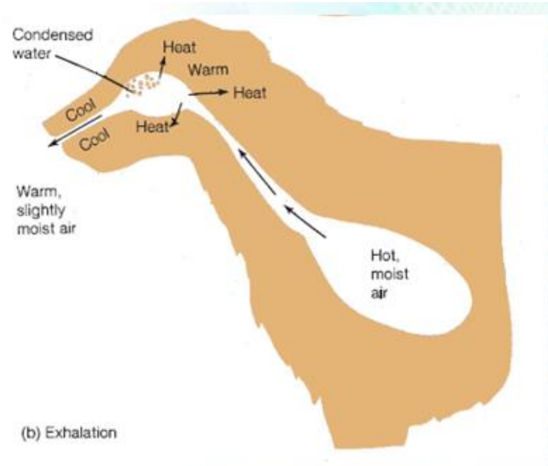
- Water can enter this frog via food, through its highly permeable skin, or from the urinary bladder.
- The skin also actively transports ions such as Na and Cl from the environment.
- The kidney forms a dilute urine by reabsorbing Na and Cl ions.
- If an amphibian becomes dehydrated, a brain hormone causes water to leave the bladder and enter the body fluid.
- When water leaves the urinary bladder, the remaining ions are reabsorbed.

Excretion in Reptiles Birds and Mammals

- Reptiles, birds, and mammals all possess metanephric kidneys.
- Their kidneys are by far the most complex animal kidneys, well suited for these animals' high rates of metabolism.
- In most reptiles, birds, and mammals, the kidneys can remove far more water than can those in amphibians, and the kidneys are the primary regulatory organs for controlling the osmotic balance of the body fluids.
- Some desert and marine reptiles and birds build up high salt (NaCl) concentrations in their bodies because they consume salty foods or seawater and they lose water through evaporation, urine and feces.
- To rid get of excess salt, the reptiles also have salt glands near the eye or in the tongue that remove excess salt from the blood and secrete it as tear-like droplets.
- A major site of water loss in mammals is the lungs.
- To reduce this evaporative loss, many mammals have nasal cavities that act as countercurrent exchange systems.
- When the animal inhales, air passes through the nasal cavities and is warmed by the surrounding tissues.
- In the process, the temperature of this tissue drops. When the air gets deep into the lungs, it is further warmed and humidified.
- During exhalation, as the warm moist air passes up the respiratory tree, it gives up its heat to the nasal cavity.
- As the air cools, much of the water condenses on the nasal surfaces.
- This mechanism explains why a dog's nose is usually cold and moist.



Inhalation



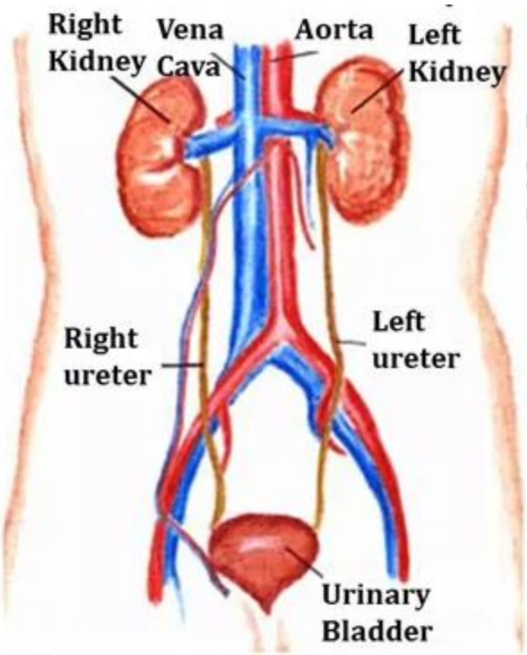
Exhalation

Excretory System of Man

- The excretory system is a biological system that removes excess, unnecessary materials from the body fluids of an organism, so as to help maintain internal chemical homeostasis and prevent damage to the body.
- The system is composed of :
    - A pair of kidneys
    - Ureters
    - Urinary bladder and urethra

Kidneys

- There is pair of kidneys situated towards the back of the lower part of the abdominal cavity on either side of the vertebral column.
- The left kidney is slightly above the right.
- The right kidney is located just below the diaphragm and posterior to the liver.
- The left kidney is situated below the diaphragm and posterior to the spleen.
- Urine from the kidneys pass by a pair of ureters to the bladder where it is stored until it is released via urethra.

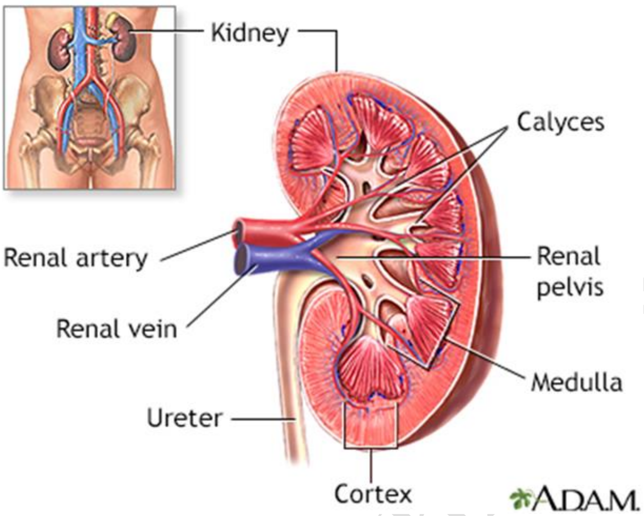


- The right kidney is located just below the diaphragm and posterior to the liver.
- The left kidney is situated below the diaphragm and posterior to the spleen.
- Urine from the kidneys pass by a pair of ureters to the bladder where it is stored until it is released via urethra.

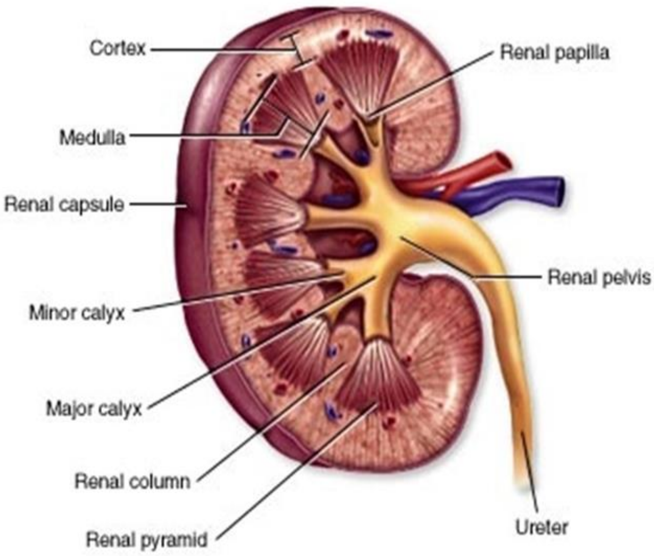
- The kidney is a bean-shaped structure with a convex and a concave border.
- A recessed area on the concave border is the renal hilum, where the renal artery enters the kidney and the renal vein and ureter leave.
- The urinary bladder is the organ that collects waste excreted by the kidneys prior to disposal by urination.
- It is a hollow muscular, and distensible (or elastic) organ, present on the pelvic floor.
- Urine enters the bladder via the ureters and streamed out via the urethra.
- Two muscle sphincters surround the urethra where it leaves the bladder.
- One of which is under voluntary control.
- These control the process of urination.

Anatomy of Human Kidney

- The kidney is divided into two major structures:
  - The outer renal cortex and the inner renal medulla.
- Grossly, these structures take the shape of 85 to 18 cone-shaped renal lobes, each containing renal cortex surrounding a portion of medulla called a renal pyramid.
- A frontal section through the kidney reveals an outer region called the renal cortex and an inner region called the medulla.
- The renal columns are connective tissue extensions that converge inward from the cortex through the medulla

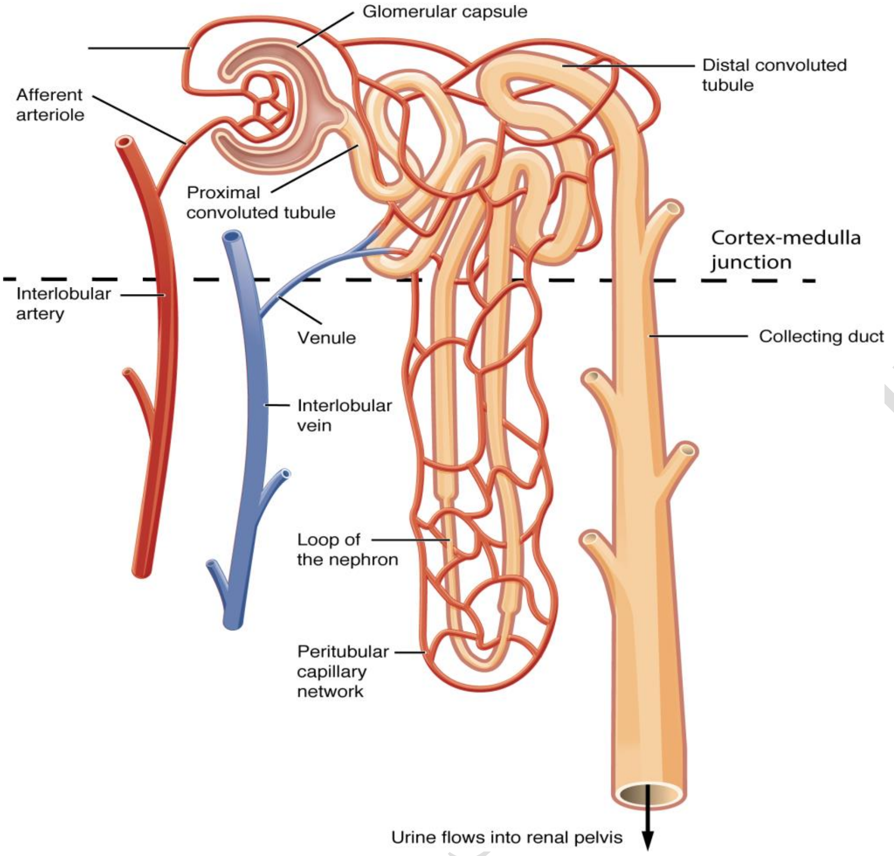


- The most characteristic features of the medulla are the renal pyramids and renal papillae
- The papillae are bundles of collecting ducts that transport urine made by nephrons to the calyces of the kidney for excretion.



Nephrons

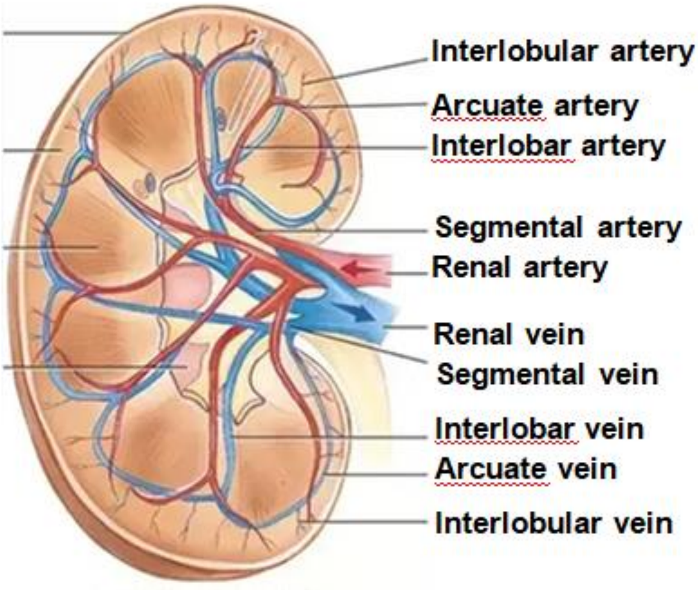
- The nephron is the structural and functional unit of the kidney, having 1 M per kidney.
- A nephron has two main parts –corpuscle and tubule.
- The cup-shaped corpuscle containing the glomerulus is called the Bowman's capsule.
- The glomerulus and Bowman's capsule together form the renal corpuscle.



- The tubules are small tubes traveling through the inner part of the kidney that regulate the passage of various chemicals to and from the blood.
- The tubule has three parts:
  - The proximal convoluted tubule.
  - U-shaped curve, the loop of Henle and
  - The distal convoluted tubule.
- The cortex is the outer renal tissue composed of:
  - The renal corpuscles, as well as the proximal and distal convoluted tubules.
- The medulla is the inner renal tissue, splitting into triangular parts called renal pyramids.
- The renal pyramids contain the loops of Henle of each renal tubule, as well as the collecting ducts.

Blood Supply to the Kidney

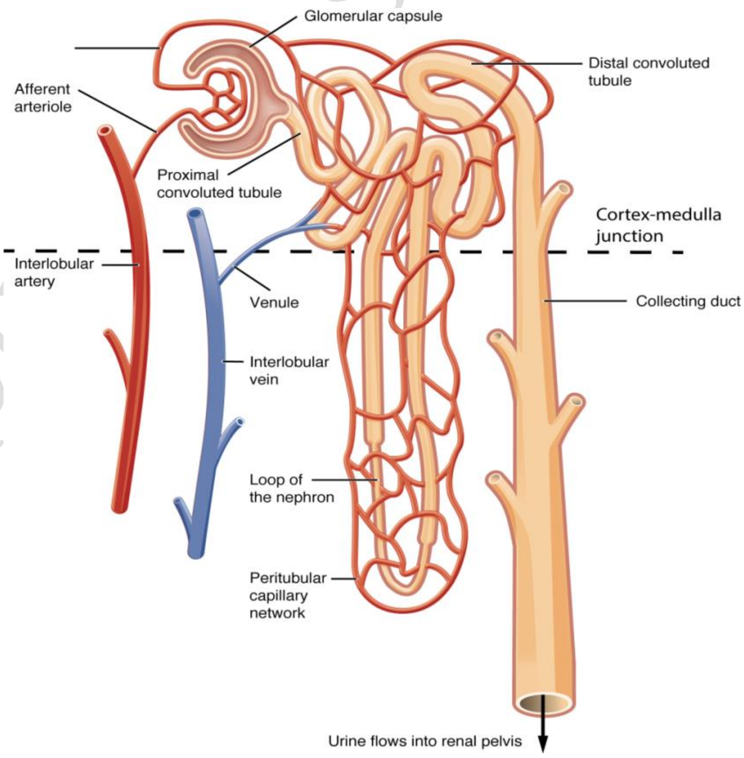
- The kidneys receive blood from the renal arteries, left and right, which branch directly from the abdominal aorta.
- Despite their relatively small size, the kidneys receive approximately 20% of the cardiac output.
- Each renal artery branches into segmental arteries, dividing further into interlobar arteries, which penetrate the renal capsule and extend through the renal columns between the renal pyramids.
- The interlobar arteries then supply blood to the arcuate arteries that run through the boundary of the cortex and the medulla.
- Each arcuate artery supplies several interlobular arteries that feed into the afferent arterioles that supply the glomeruli.



- Blood drains from the kidneys, ultimately into the inferior vena cava.
- After filtration occurs, the blood moves through a small network of small veins (venules) that converge into interlobular veins.
- As with the arteriole distribution, the veins follow the same pattern: the interlobular provide blood to the arcuate veins then back to the interlobar veins, which come to form the renal veins which exiting the kidney.

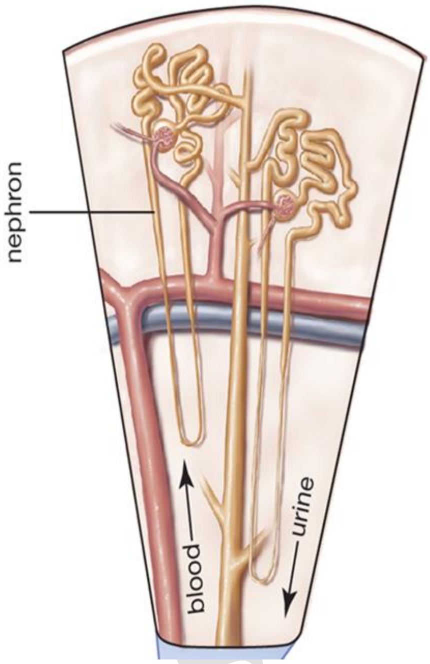
Structure of Nephron

- The nephron is the structural and functional unit of the kidney, having 1 M per kidney.
- A nephron has two main parts –corpuscle and tubule.
- The cup-shaped corpuscle containing the glomerulus is called the Bowman's capsule.
- The glomerulus and Bowman's capsule together form the renal corpuscle.



- Nephron is a long tube-like structure, having varying from 35–55 mm long.
- At one end, the tube is expanded, closed, and, folds into a double-walled, a cuplike structure called the Bowman's capsule or renal capsule, which encloses a cluster of microscopic blood vessels called the glomerulus.

- The first part is called the proximal convoluted tubule (PCT) it stays in the renal cortex.
- The second part is called the loop of Henle, (with descending and ascending limbs) that goes through the renal medulla.
- The third part of the renal tubule the distal convoluted tubule (DCT) and this part is also restricted to the renal cortex.



- The cortex is the outer renal tissue which is composed of:
  - The renal corpuscles, as well as the proximal and distal convoluted tubules.
  - The medulla is the inner renal tissue, splitting into triangular parts called renal pyramids.
  - The renal pyramids contain the loops of Henle of each renal tubule, as well as the collecting ducts.

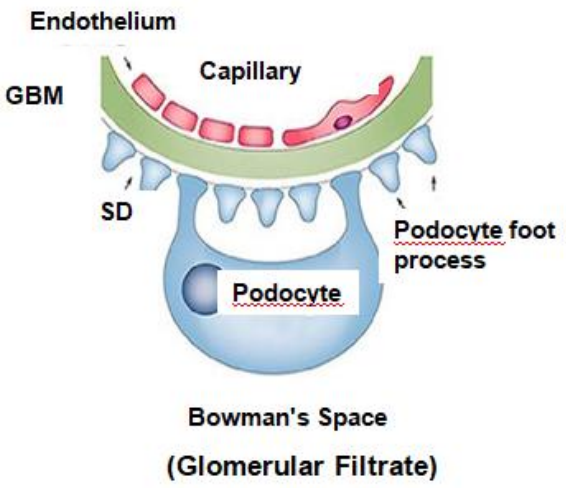
Functioning of the Nephron

- The structure and function of the epithelial cells lining the lumen of the nephron change during the course of the nephron, and have segments named by their location which reflects three different functions:
  - Filtration
  - Reabsorption
  - Secretion

Filtration:

- The glomerulus is the tuft of filtering capillaries located in Bowman's capsule.
- Each glomerulus receives blood supply from an afferent arteriole of the renal circulation.
- The glomerular blood pressure provides the driving force for water and solutes to be filtered out of the blood plasma.

- The wall through which the blood filters has a unique structure:
- It is composed of three layers:
  - Capillary endothelium,
  - Basement membrane, and
  - Epithelium (podocytes) of Bowman's capsule
- The filtrate comes into the space called Bowman's space.
- After passing through the endothelial cells of the capillaries, the glomerular basement membrane GBM, and between podocyte foot processes, the filtrate enters the capsule as ultrafiltrate or glomerular filtrate.
- The filtrate contains:
  - Glucose, amino acids, ions (Ca^{++}, PO_4^{3-}) and the primary nitrogenous wastes i.e. urea or uric acid.



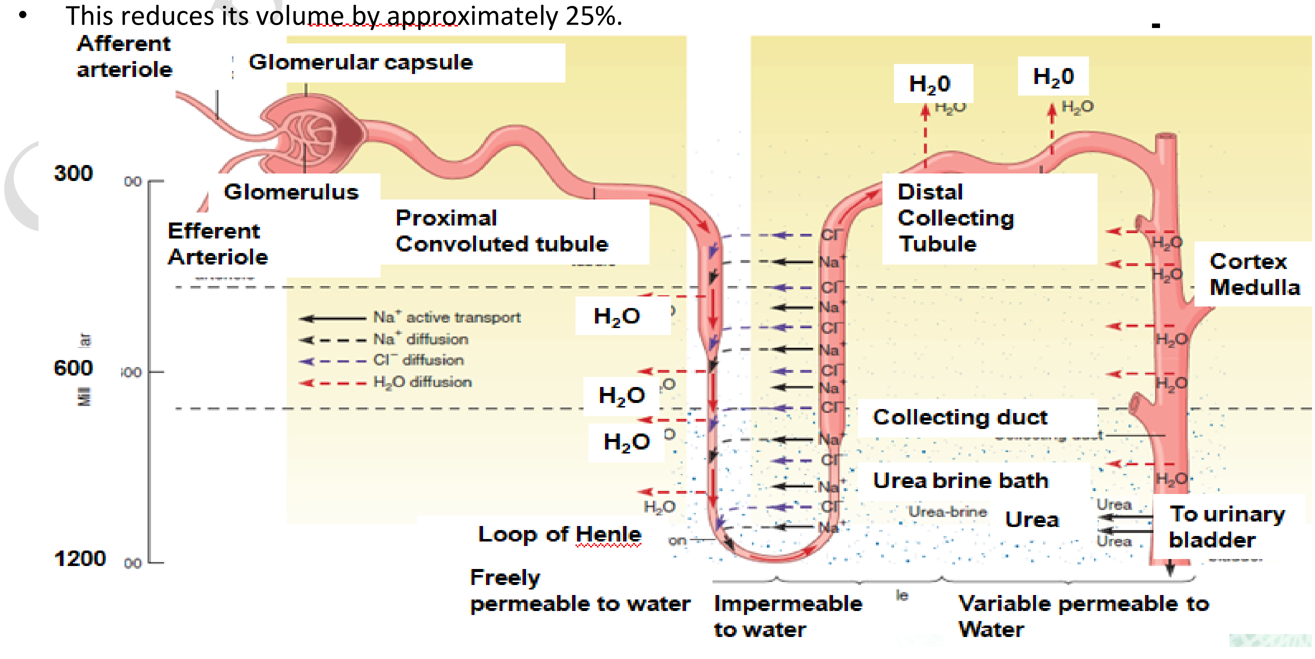
Loop of Henle as Counter Current Multiplier

Countercurrent Exchange

- The Loop of Henle increases the efficiency of reabsorption by countercurrent flow similar to that in the gills of fishes.
- Generally, the longer the loop of Henle, the more water and ions that can be reabsorbed.

It follows that:

- Amphibians lack the loop because that are closely associated with aquatic habitats.
- Desert rodents (e.g., the kangaroo rat) that live in dry conditions have very long nephron loops and form highly concentrated urine.
- The diagram next, shows the countercurrent flow mechanism for concentrating urine.
- The process of reabsorption in the proximal convoluted tubule removes water and some salt (NaCl) from the glomerular filtrate.
- This reduces its volume by approximately 25%.



- However, the concentrations of salt and urea are still isosmotic with the extracellular fluid.
- As the filtrate moves to the descending limb of the loop it becomes further reduced in volume and more concentrated.
- Water moves out of the tubule by osmosis due to the high salt concentration (the "brine-bath") in the extracellular fluid.
- The highest urea-brine bath concentration is around the lower portion of the loop of the nephron.
- As the filtrate passes into the ascending limb, sodium (Na) ions are actively transported out of the filtrate into the extracellular fluid, with chloride (Cl) ions following passively.
- Water cannot flow out of the ascending limb because the cells of the ascending limb are impermeable to water.

Overall Functioning of the Metanephric Kidney

- Metanephric Kidneys corresponds to the mature and functional kidney in higher vertebrates.
- The metanephros plays an important role in the urogenital system.
- Following are the chief functions :
    1. Electrolyte balancing,
    2. Blood filtering
    3. BP regulation
    4. Formation of urine
- To make urine, three physiological mechanisms are involved:
    - Filtration of plasma
    - Reabsorption of needed materials
    - Secretion of a few substances, such as potassium and hydrogen ions, into the renal tubule.
- About 99% of the filtrate is reabsorbed from the renal tubules into the blood.
- Reabsorption is a highly selective process that returns usable materials to the blood but leaves wastes and excesses of other substances to be excreted in the urine.
- In secretion, hydrogen ions, certain other ions, and some drugs are actively transported into the renal tubule to become part of the urine.
- Production of concentrated urine depends on a high salt and urea concentration in the interstitial fluid of the kidney medulla.
- A counter flow of fluid through the two limbs of the loop of Henle concentrates filtrate as it moves down the descending loop and dilutes it as it moves up the ascending loop.
- Water is drawn by osmosis from the filtrate as it passes through the collecting ducts.
- This process concentrates urine in the collecting ducts.
- Urine is a watery solution of nitrogenous wastes, excess salts, and other substances not needed by the body.

How Various Vertebrates Maintain Water and Salt Balance?

Freshwater Fishes

- Environmental Concentration relative to body fluids is hypoosmotic.
- Urine concentration relative to blood is hypoosmotic.
- Major nitrogenous waste is ammonia.
- Key adaptation: absorb ions through gills.

Seawater Fishes

- Environmental Concentration relative to body fluids is hyperosmotic.
- Urine concentration relative to blood is isoosmotic.
- Major nitrogenous waste is ammonia.
- Key adaptation: secrete ions through gills.

Sharks

- Environmental Concentration relative to body fluids is isoosmotic.
- Urine concentration relative to blood is isoosmotic.
- Major nitrogenous waste is ammonia.
- Key adaptation: secrete ions through rectal glands.

Amphibians

- Environmental Concentration relative to body fluids is hypoosmotic.
- Urine concentration relative to blood is very hypoosmotic.
- Major nitrogenous waste is ammonia and urea.
- Key adaptation: absorb ions through skin.

Marine reptiles

- Environmental Concentration relative to body fluids is hyperosmotic.
- Urine concentration relative to blood is isoosmotic.
- Major nitrogenous waste is ammonia and urea.
- Key adaptation: secrete ions through salt glands.

Marine Mammals

- Environmental Concentration relative to body fluids is hyperosmotic.
- Urine concentration relative to blood is very hyperosmotic.
- Major nitrogenous waste is urea.
- Key adaptation: drink some water.

Desert Mammals

- Environmental Concentration relative to body fluids is no comparison.
- Urine concentration relative to blood is very hyperosmotic..
- Major nitrogenous waste is ammonia and urea.
- Key adaptation: produce metabolic water.

Marine reptiles

- Environmental Concentration relative to body fluids is no comparison.
- Urine concentration relative to blood is weakly hyperosmotic.
- Major nitrogenous waste is uric acid.
- Key adaptation: drink sea water and use salt glands.

Terrestrial Birds

- Environmental Concentration relative to body fluids is no comparison.
- Urine concentration relative to blood is weakly hyperosmotic.
- Major nitrogenous waste is uric acid.
- Key adaptation: drink fresh water.

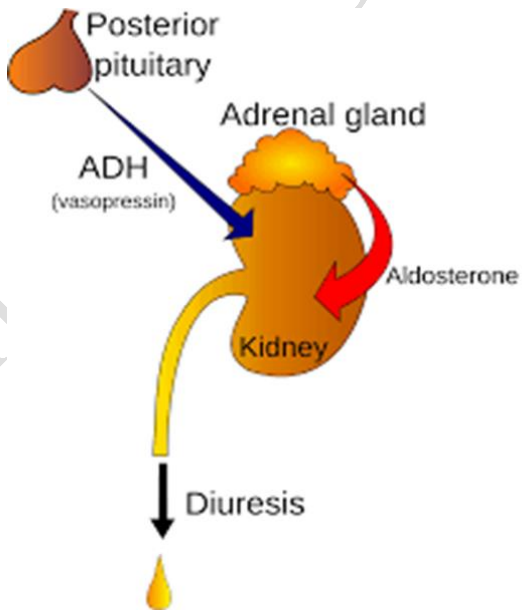
Hormonal Control of Kidney Function

The Kidneys

- Maintain fluid volume and electrolyte concentration.
- They help maintain the concentration of Na^+ and K^+ in the blood within narrow limits and also regulate blood pH.
- There are many hormones that regulate the homeostatic functions of the kidney.
- These are:
  - Renin
  - Angiotensin
  - Aldosterone
  - Endothelin
  - Natriuretic Hormones
  - Parathyroid Hormone
  - Antidiuretic Hormone (ADH)
- Here we discuss only ADH.

ADH increases water reabsorption

- The amount of urine produced depends on the body's need of water.
- When fluid intake is low, the body begins to dehydrate, and the blood volume decreases.
- As blood volume decreases, the concentration of salts in the blood becomes greater, causing an increase in osmotic pressure.
- Certain receptors in the hypothalamus are sensitive to this osmotic change.
- They signal the posterior lobe of the pituitary gland to release antidiuretic hormone (ADH).
- ADH makes the collecting ducts more permeable to water so that more water is reabsorbed.
- As a result, a small volume of concentrated urine is produced.



- When we drink a large volume of water, our blood becomes diluted and its osmotic pressure falls.
- This condition inhibits the release of ADH, and decrease in reabsorption of water from the collecting ducts.
- The kidneys then produce a large volume of dilute urine.
- In diabetes insipidus, the pituitary gland malfunctions and does not release enough ADH.
- A person with severe diabetes insipidus may excrete up to 25 quarts of urine each day, a serious water loss.
- The affected individual becomes dehydrated and must drink almost continually to counterbalance fluid loss.
- Injections of ADH or use of an ADH nasal spray can often control diabetes insipidus.

Common Disorders of Human Excretory System

Excretory System consists of:

- Kidneys,
- Ureters,
- Urinary bladder and
- Urethra.

Examples of urinary disorders:

- Kidney failure
- Kidney stones
- Urinary tract infections
- Hydronephrosis
- Polycystic Kidney disease
- Uremia
- Inability to control urine flow
- Hypertension due to Renin Secretion
- Diabetes Insipidus

Kidney failure

- Kidney failure means when they stop working well enough for survival without dialysis or a kidney transplant.
- Kidney failure the last stage of chronic kidney disease.
- Complete and irreversible kidney failure is sometimes called end-stage renal disease, or ESRD.
- When kidneys stop working completely, the body fills with extra water and waste products.
- This condition is called uremia.
- Untreated uremia may lead to death.

Kidney Stones

- Kidney stones are hard deposits made of minerals and salt that form inside the kidneys. Also called renal calculi.
- Main causes of kidney stone formation are:
- Diet, obesity, certain supplements, and sometimes medications.
- Kidney stones are formed when urine contains more crystal-forming substances — such as calcium, oxalate and uric acid.
- At the same time, urine may lack substances that prevent crystals from sticking together, creating an ideal environment for kidney stones to form.

Types of Kidney Stones

- Calcium Oxalate Stones. (The most common type of kidney stone.)
- Calcium Phosphate Stones.
- Uric Acid Stones.
- Cystine Stones.

Lithotripsy

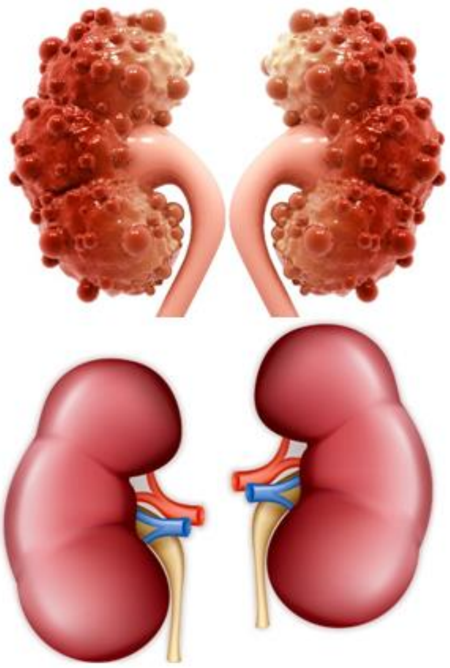
- It is a procedure that uses shock waves or LASER *(Light Amplification by Stimulated Emission of Radiation)* to break up stones into small particles in the kidney and parts of the ureter.
- The particles of small stone then exit the body when a person urinates.

Urinary Tract Infection

- A urinary tract infection (UTI) is an infection in any part of the urinary system —kidneys, ureters, bladder and urethra.
- Most infections involve the lower urinary tract — the bladder and the urethra.
- Women are at greater risk of developing UTI than men.
- UTI is caused by microorganisms — usually bacteria — that enter the urethra and bladder, causing inflammation and infection.
- Though UTI most commonly happens in the urethra and bladder, bacteria can also travel up the ureters and infect the kidneys.
- Some signs of UTI include:
  - cloudy urine
  - painful urination
  - burning with urination
  - a weak urine stream
  - back pain and fever

Natural Remedy of UTI

- Drinking lot of water
- Emptying bladder when needed.
- Eat Vitamin C that help destroy bad bacteria due to its acidity.
- Vitamin C also help protect from future infections



Polycystic kidney disease (PKD)

- It is an inherited disorder in which clusters of cysts develop within the kidneys, causing kidneys to enlarge and lose function over time.
- Cysts are noncancerous round sacs containing fluid.
- The growth of cysts causes the kidneys to become enlarged and can lead to kidney failure.
- UTIs are one of the most common complications of hydronephrosis.

Hydronephrosis

- Hydronephrosis is a condition that typically occurs when a kidney swells due to urine failing to properly drain from the kidney to the bladder.
- This swelling most commonly affects only one kidney, but it can involve both kidneys.
- Hydronephrosis is not a primary disease.
- It is a secondary condition that results from some other underlying disease.
- It is the result of a blockage or obstruction in the urinary tract.
- Hydronephrosis is said to affect about 1 in every 100 babies.
- Normally, urine flows through the urinary tract with minimal pressure.
- Pressure can build up if there is an obstruction in the urinary tract.
- If this pressure remains build up for an extended period, kidney can enlarge.
- Kidney may become so enlarged with urine that it starts pressing nearby organs.
- If it is left untreated for too long, this pressure can cause kidneys to lose function permanently.

Chapter#3
Reproduction

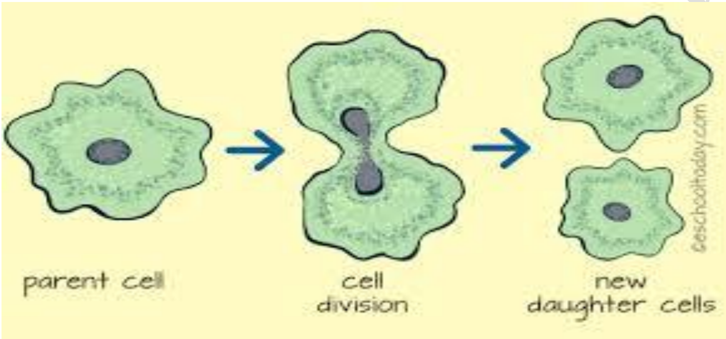
Asexual Reproduction in Invertebrates

Asexual Reproduction:

- Following are the forms:
    - Fission
        a. binary fission
        b. multiple fission
    - Budding (both internal and external)
    - Fragmentation
    - Parthenogenesis

Binary Fission:

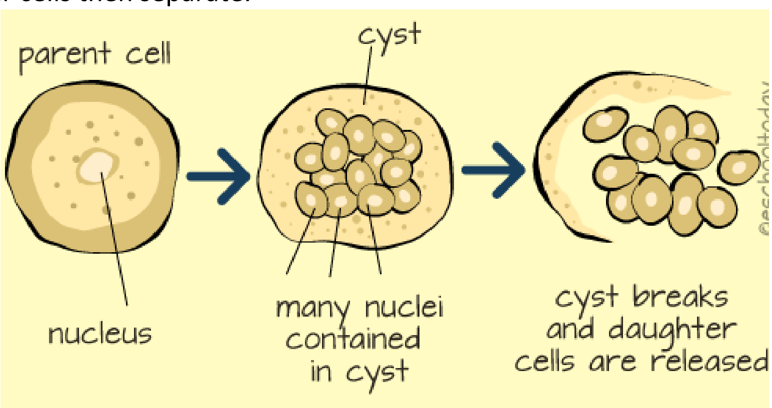
- Binary Fission is the division of one cell, body, or body part into two.
- In this process, the *Amoeba* pinches in two by an inward furrowing of the plasma membrane.
- Binary fission is common in protozoa (*Amoeba, Plasmodium, Paramecium* etc)



- In fission, the plane of division may be asymmetrical, transverse, or longitudinal, depending on the species.
- For example*, Planarian* reproduce by longitudinal fission

Multiple fission:

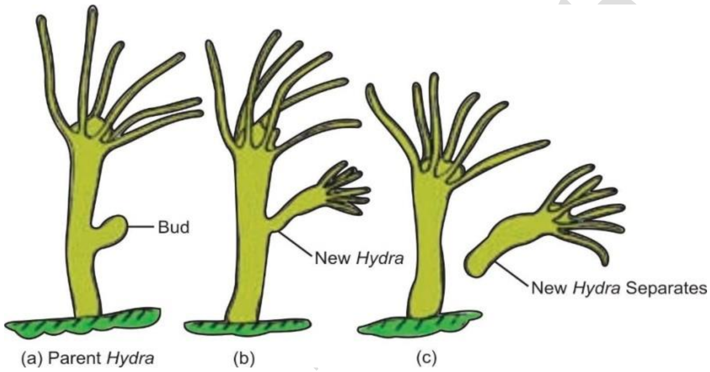
- In this process, the nucleus divides mitotically to produce a large number of nuclei before the cell divides.
- Each nucleus, with the surrounding cytoplasm, forms a daughter cell.
- These daughter cells then separate.



- Some flatworms and annelids reproduce by forming numerous constrictions along the length of the body; a chain of daughter individuals results This type of asexual reproduction is an other example of multiple fission

Budding

- Budding is a form of asexual reproduction that results from the outgrowth of body region leading to a separation from the original organism into two individuals.
- It may be external or internal.
  - External Budding occurs commonly in some invertebrate animals such as corals and hydras.



  - The bud cells proliferate to form a cylindrical structure, which develops into a new animal, usually breaking away from the parent.
  - If the buds remain attached to the parent, they form a colony.

  - Internal budding is by the formation of gemmules which are collections of many cells surrounded by a body wall.
  - When the body of the parent dies and degenerates, each gemmule gives rise to a new individual.
  - Example is freshwater sponges.

Fragmentation

- Fragmentation is a type of asexual reproduction that occurs in some cnidarians, platyhelminths, and echinoderms.
- For example, in sea anemones, as the organism moves, small pieces break off from the adult which develop into new individuals

Parthenogenesis

- Parthenogenesis is a form of asexual reproduction in which development of egg occurs without being fertilized.

Types of Parthenogenesis:

- Diploid Parthenogenesis
- Haploid Parthenogenesis

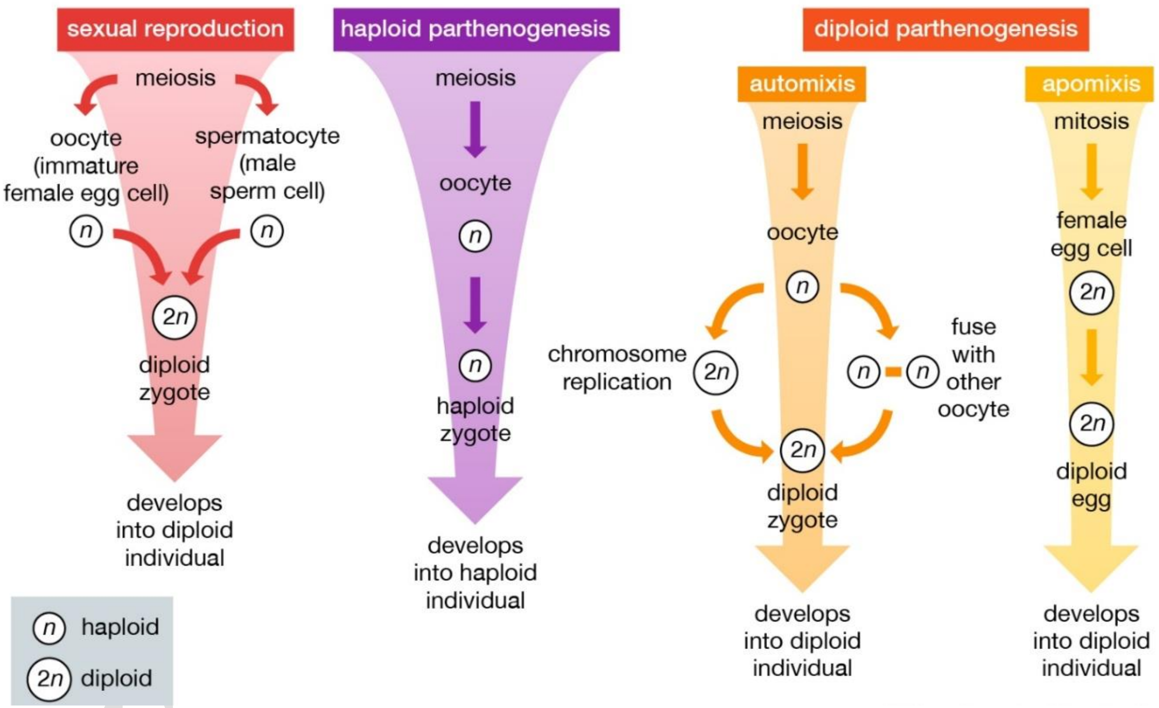
Diploid Parthenogenesis:

- In this type, no meiosis occurs and the eggs are formed by mitosis.
- The eggs develop and the offspring are the copies or clones of the parents.
- In some cases egg are formed by modified form of meiosis involving total non-disjunction of the chromosomes thus retaining the diploid number.
- Such eggs develop into young females.
- Examples: some species of flat worm, rotifers and insects.

Haploid Parthenogenesis:

- In this type of Parthenogenesis haploid ova are formed by meiosis and they may or may not be fertilized by sperm.
- If fertilized, the zygotes develop into females (Queen or sterile female workers in bee).
- If unfertilized the eggs develop to become haploid males (drones). On maturity they produce sperms by mitosis.

The process of sexual reproduction versus several forms of parthenogenesis



- Overall, animals that reproduce parthenogenetically have substantially less genetic variability than do animals with chromosome sets from two parents.
- Parthenogenesis also plays an important role in social organization in colonies of certain bees, wasps, and ants.
- Parthenogenesis has the advantage of accelerating the rate of reproduction.
- In fact, mature eggs of species that do not undergo parthenogenesis can sometimes be activated to develop without fertilization by pricking them with a needle, by exposing them to high concentrations of calcium, or by altering their temperature.

Advantages and Disadvantages of Asexual Reproduction

Advantages:

1. Large numbers of offspring are produced very quickly from only one parent when conditions are favorable.
2. Large colonies can form that can out compete other organisms for nutrients and water.
3. Large number of organisms mean that species may survive when conditions or number of predators change.
4. Energy is not required to find mate.

Disadvantage

1. Offspring are genetic clones.
2. A negative mutation can make asexually produced organisms susceptible to disease and can destroy large number of offspring.
3. Some methods of asexual reproduction produce offspring that are closetogether and compete for food and space.
4. Unfavorable conditions such as extreme temperatures can wipe out entire colonies.

Fertilization and its Types

Fertilization

- Fertilization is the fusion of haploid gametes, egg and sperm, to form the diploid zygote.
- There are delicate differences in the fertilization process which occurs naturally within the body or through reproductive technologies outside the body.
- In both cases diploid zygote is formed.

Stages of Fertilization Process:

1) sperm and egg preparation,
2) sperm-egg recognition
3) fusion of sperm and egg membranes
4) Penetration of sperm nucleus into the egg.
5) Fusion of pronuclei and activation of the zygote.

Types of fertilization

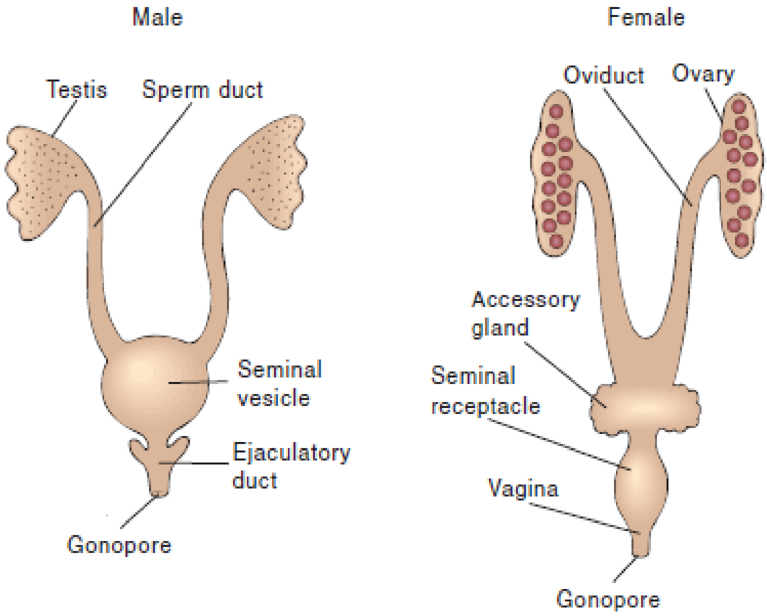
- External fertilization
  - Fertilization out of the body i.e. in water.
- Internal fertilization
  - In this type of fertilization the eggs are fertilized within the female reproductive tract.

External Fertilization

- It is a mode of reproduction in which a male organism's sperm fertilizes a female organism's egg outside of the female's body.
- The release of eggs and sperm into the water is known as spawning.
- Many invertebrates (e.g., sponges and corals) simply release their gametes into the water in which they live allowing external fertilization to occur.
- In these invertebrates, the transient structures, such as coelomic ducts, metanephridia, sperm ducts, or oviducts are used to release gametes from the body.
- Invertebrates utilizing external fertilization are mostly benthic, sessile, or both, including animals such as coral, sea anemones, and tube-dwelling polychaetes.
- Among vertebrates, external fertilization is most common in amphibians and fish.

Internal Fertilization

- Internal fertilization is the union of an egg cell with a sperm during sexual reproduction inside the female body.
- For this to happen there needs to be a method for the male to introduce the sperm into the female's reproductive tract.
- In some invertebrates (e.g., arrow worms, leeches, some insects) the sperms are produced in the testes and transported via a sperm duct to a storage packet area called spermatophores.
- Spermatophores provide a protective casing for sperms and facilitate the transfer of large numbers of sperm with minimal loss.
- Some spermatophores are even motile and act as independent sperm carriers.
- Sperm or the spermatophores are then passed into an ejaculatory duct to a copulatory organ (e.g. cirrus, gonopore).
- The copulatory organ is used as an intromittent structure to introduce sperm into the female's system.



- Various accessory glands (e.g., seminal vesicle) may be present in males that produce seminal fluid.
- In the female, ova (eggs) are produced in the ovaries and transported to the oviduct.
- Sperm move up the oviduct, where they encounter the ova and fertilize them.
- Accessory glands (e.g.,those that produce egg capsules or shells) may also be present in females.
- In some sexually reproducing animals occasionally depart from this basic reproductive mode and exhibit variant forms of sexual reproduction.
- The various forms of sexual reproduction are:
  - Hermaphroditism
  - Sequential hermaphroditism

Hermaphroditism

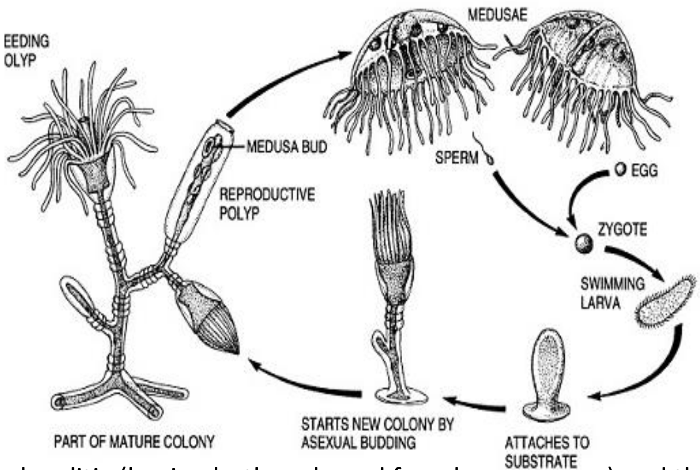
- Hermaphroditism, is the condition of having both male and female reproductive organs.
- Hermaphroditic animals are mostly invertebrates such as worms, bryozoans, trematodes (flukes), snails, slugs, and barnacles.
- They are usually parasitic, slow-moving, or permanently attached to another animal or plant.
- Hermaphroditism is especially beneficial to sessile animals that occasionally encounter the opposite sex.

- Another variation is sequential hermaphroditism.
- This occurs when an animal is one sex during one phase of its life cycle and the opposite sex during another phase.
- Hermaphrodites are either Protogynous or Protandrous
- Protogynous animals are born female and at some point of their life span change sex to males.
    - Examples: *Bluehead wrasses, Rana temporaria.*
- Protandrous animals are male during their early life history and female later in the life history.
    - Examples: *Many fish, mollusks, and crustaceans.*
- A change in the sex ratio of a population is one factor that can induce sequential hermaphroditism, which is common in oysters.

Sexual Reproduction in Invertebrates

Sexual Reproduction:

- Most invertebrates reproduce partly through sexual reproduction.
- They produce specialized reproductive cells that undergo meiosis to produce smaller, motile spermatozoa or larger, non-motile ova.
- These fuse to form zygotes, which develop into new individuals.
- Cnidarians usually reproduce sexually, using eggs and sperms (Medusae).
- Depending on the species, cnidarians can be monoecious (also called hermaphroditic), with individuals capable of producing both eggs and sperm, or they can be dioecious, with individuals of separate sexes for gamete production.



- Flatworms are hermaphroditic (having both male and female sex organs) and they typically reproduce both sexually and asexually.
- The majority of sexual reproduction is through cross-fertilization (where both individuals fertilize each other).
- Polychaete species normally have separate sexes, while most oligochaetes are hermaphrodites.
- In hermaphroditic species, each individual has both male and female sex organs.
- Arthropods have a great diversity in sexual reproduction.
- A few species of insects such as honey bee reproduce by parthenogenesis.
- Aquatic arthropods may breed by external fertilization, as frogs do, or by internal fertilization.
- All known terrestrial arthropods are dioceous and use internal fertilization.
- Once the eggs are fertilized, the female usually lays the egg, and continues developing outside of the mother's body.
- Most male terrestrial arthropods produce waterproof sperm packets, spermatophores,, which the females take into their bodies.
- Most arthropods lay eggs, but scorpions are ovoviparous: they produce live young after the eggs have hatched inside the mother, and are noted for prolonged maternal care.

Advantages & Disadvantages of Sexual Reproduction

Advantages

- Offspring are genetically unique because of crossing over, Independent assortment and random fusion of gametes.
- Slower rate of reproduction but faster adaptation/evolution.
- Favorable when the environment is not stable.
- Lower extinction rate.
- Fast removal of bad mutations.
- Better adaptation to host- parasite race.
- Offspring are dispersed widely to end up in different places from their parents.

Disadvantages

- Slower reproductive rate, fewer offspring are produced over longer time span.
- Potential for spread of sexually transmitted diseases through population.
- Energetically costly, i.e. requires a lot of ongoing energy input from the parent.

Sexual Reproduction in Vertebrates

- Sexual reproduction in animals involves the production and fusion of two types of gametes—sperm and eggs.
- Typically, two different individuals are required.
- A male parent contributes sperm, and a female parent contributes an egg, or ovum.
- The sperm provides genes coding for some of the male parent's traits, and the egg contributes genes coding for some of the female parent's traits.
- The egg is typically large and non-motile; with a store of nutrients that supports the development of the embryo.
- The sperm is usually small and motile and adapted to propel itself by beating its long, whip-like flagellum.
- When sperm and egg unite, a zygote, or fertilized egg, is produced.
- The zygote develops into a new animal, similar to both parents but not identical to either.
- Sexual reproduction typically involves remarkably complex structural, functional, and behavioral processes.
- The strong drive to mate or reproduce dominates the lives of many vertebrates.
- Females of most mammal species come into heat or estrus about the same time each year.
- Genetic, hormonal, and nervous system controls the estrus cycle so that the young are born when environmental conditions are favorable.

Basic Reproductive Strategies in Vertebrate

- Fishes have various reproductive methods, structures, and physiology to adapt themselves to a great variety of aquatic habitats.
- High fecundity i.e. releasing of eggs in thousands to millions. is well known strategy.
- Cod fish for example releases about five million eggs in a single spawn.
- In Amphibians the reproductive strategies are much more diverse than those observed in other groups of vertebrates.
- Anurans (toads and frogs) for example have a variety of reproductive adaptations towards terrestriality.
- Ovoviviparity, and Viviparity are the adaptations for successful invasion of mountainous environments by amphibians.
- A few frogs and toads, the fire salamander and several species of caecilians, are viviparous.
- These adaptations are evolutionary conquest of terrestrial environments by vertebrates.

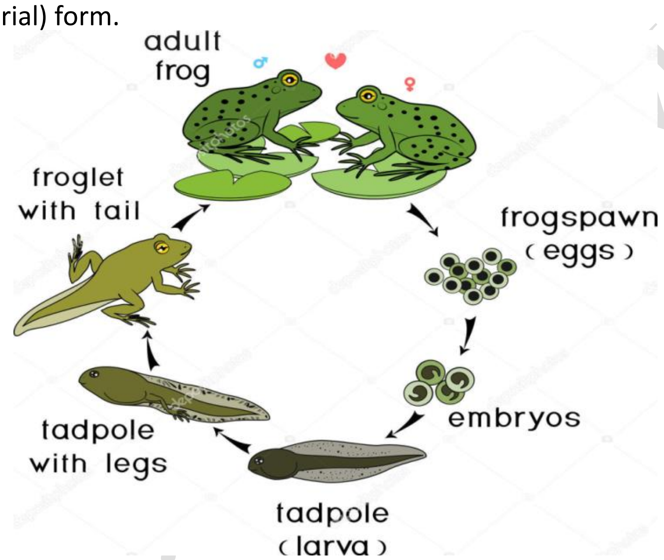

- Reptiles, Birds, and early mammals exhibit reproductive adaptations of advanced mammals including humans.
- The reptilian system includes:
  - Shelled, desiccation-resistant eggs.
  - Three basic embryonic membranes.
  - Flat embryo.
  - Gastrulation atop a huge yolk mass.
- The same process of gastrulation is seen in mammalian embryos even though the massive yolk mass has been lost.
- During gestation the embryo is nourished with nutrients and oxygen, and protected from any attack by the mother's immune system.
- After birth, the mammals nurse their young with milk from the mammary glands, just as primates do today.
- Female apes and monkeys mate only when in estrus, increasing the probability of fertilization.
- Human females show a less distinctive estrus phase and can reproduce throughout the year.
- They can also engage in sexual activity without reproductive purpose.

Reproduction in Fishes

- All fishes reproduce in aquatic environments.
- In bony fishes, fertilization is usually external, and eggs contain only enough yolk to sustain the developing fish for a short time.
- After the yolk is consumed, the growing fish must seek food.
- Although many thousands of eggs are produced and fertilized, few survive and grow to maturity.
- Some succumb to fungal and bacterial infections, others to siltation and still others to predation.
- To assure reproductive success, the fertilized egg develops rapidly, and the young achieve maturity within a short time.

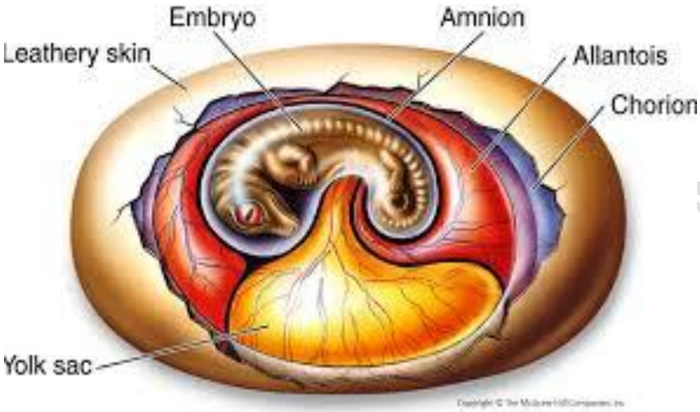
Reproduction in Amphibians

- The amphibians were the first vertebrates to invade the land.
- They have not, however, become adapted to a completely terrestrial environment; their life cycle is still inseparably linked to water.
- Among most amphibians, fertilization is still external, just as it is among the fishes.
- Among the frogs and toads, the male grasps the female and discharges fluid containing sperm onto the eggs as she releases them into the water.
- The developmental period is much longer in amphibians than in fishes, although the eggs do not contain appreciably more yolk.
- An evolutionary adaptation present in amphibians is the presence of two periods of development: larval and adult stages.
- The aquatic larval stage develops rapidly, and the animal spends much time eating and growing.
- After reaching a sufficient size, the larval form undergoes a developmental transition called metamorphosis into the adult (often terrestrial) form.



Reproduction in Reptiles

- The reptiles were the first group of vertebrates to completely abandon the aquatic habitat because of adaptations that permitted sexual reproduction on land.
- A crucial adaptation first found in reptiles is internal fertilization.
- Internal fertilization protects the gametes from drying out, freeing the animals from returning to water to breed.
- Many reptiles are oviparous, and the eggs are deposited outside the body of the female.
- Others are ovoviviparous.
- They form eggs that hatch in the body of the female, and the young are born alive.
- The shelled egg and extra mbryonic membranes, also first seen in reptiles, constitute two other important evolutionary adaptations to life on land.
- These adaptations allowed reptiles to lay eggs in dry places without danger of desiccation.
- As the embryo develops, the extra embryonic chorion and amnion help protect it, the latter by creating a fluid-filled sac for the embryo.
- The allantois permits gas exchange and stores excretory products.
- Complete development can occur within the eggshell.
- When the animal hatches, it has developed to the point that it can survive on its own or with some parental care.



Reproduction in Birds

- Birds have retained the important adaptations for life on land that evolved in the early reptiles.
- With the exception of most waterfowl, birds lack a penis.
- Males simply deposit semen against the cloaca for internal fertilization.
- Sperm then migrate up the cloaca and fertilize the eggs before hard shells form.
- All birds are oviparous, and the eggshells are much thicker than those of reptiles.
- Thicker shells permit birds to sit on their eggs and warm them.
- This brooding, or incubation, hastens embryo development.
- When many young birds hatch, they are incapable of surviving by their own.
- Extensive parental care and feeding of young are more common among birds than fishes, amphibians, or reptiles.

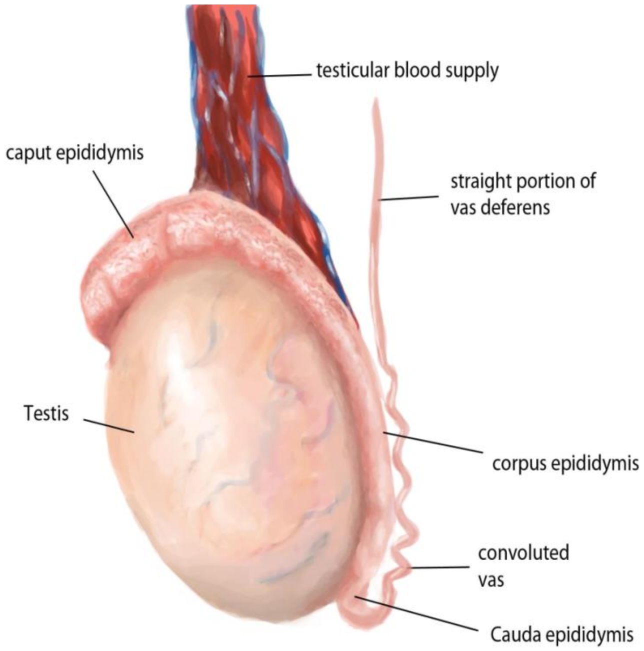
Reproduction in Mammals

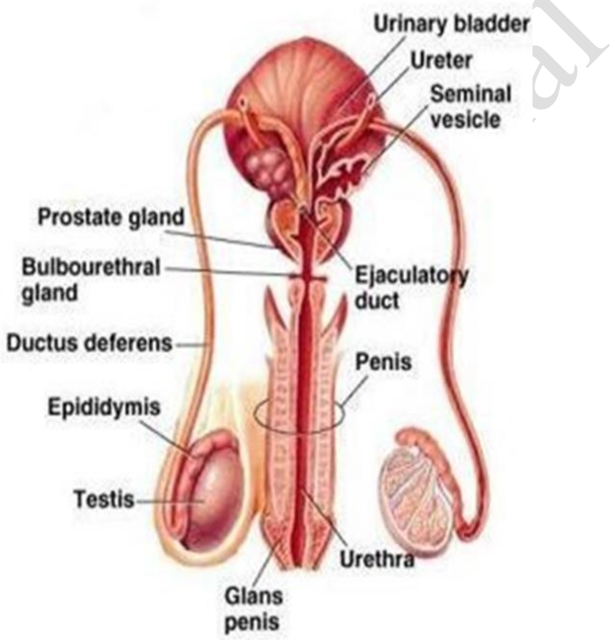
- The most primitive mammals, the monotremes (e.g., the duckbilled platypus and spiny anteater), lay eggs, as do the reptiles from which they evolved.
- All other mammals are viviparous.
- Mammalian viviparity was another major evolutionary adaptation, and it has taken two forms.


- The Marsupials developed the ability to nourish their young in a pouch after a short gestation inside the female.
- The Placentals much larger group, retain the young inside the female, where the mother nourishes them by means of a placenta.
- Even after birth, mammals continue to nourish their young.
- Some mammals nurture their young until adulthood, until they are able to secure for themselves.

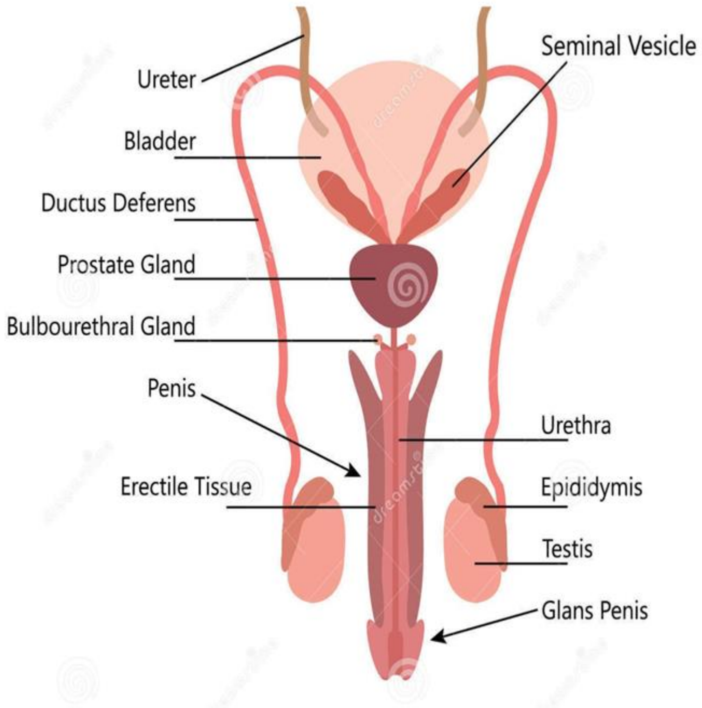
Human Male Reproductive System

- The main function of the male reproductive system is to produce sperms and male sex hormone for fertilization of the ovum.
- The male reproductive system can be divided into three categories.
    - The first category consists of organs located outside the body produces and stores sperms.
    - These are produced in the testes, which are housed in the temperature-regulating pocket, scrotum.
    - Immature sperms travel to the epididymis for development and storage.
    - The testes also produce the male sex hormone, the testosterone.





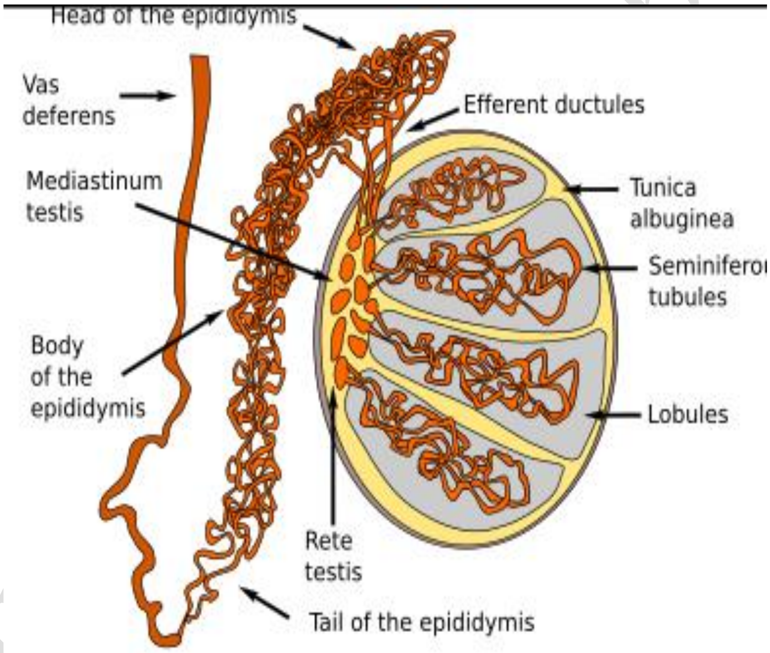
- The second category are the structures located around the pelvis region of male.
- These structures include fluid producing glands (bulbo-urethral gland, seminal vesicles, prostate gland) and ductus deferense.



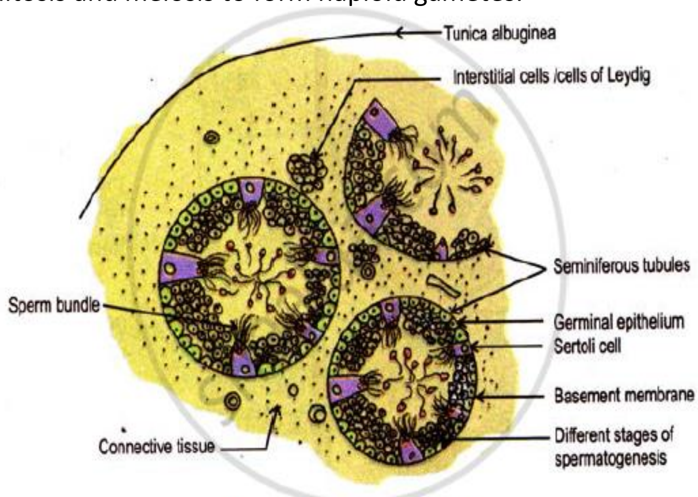
- The third category is those used for copulation and deposition of semen in the vagina (the penis and urethra).

Histology of Human Testis

- Each testis is covered by a thick capsule called Tunica Albuginea.
- It is composed mainly of collagenous fibers and smooth muscle cells.
- Posteriorly the tunica albuginea is thickened and is called mediastinum testis.
- Thin fibrous septa, called Septula testis, radiate from the midiastinum to the capsule and divide the interior of the testis into 200 to 300 Pyramidal Lobules.
- The septula are not complete partitions; they show numerous gaps, through which the testicular lobules communicate quite freely.
- Beneath the tunica albuginea there is a layer of loose areolar connective tissue containing networks of blood vessels.
- This layer is known as tunica vasculosa, also lines the Septula Testis.
- Each testicular lobule contains 1-4 highly convoluted Seminiferous Tubules,
- Each seminiferous tubule is intricately coiled, averaging about 0.2 mm diameter and 50 cm in length.
- Individual tubules usually commence as free blind ends but neighboring tubules may form anastomosing loops.
- At the apex of the testicular lobule seminiferous tubules lose their convolutions and become straight.
- This makes the initial part of the male genital duct system.
- Seminiferous tubules are lined by a complex Germinal Epithelium.

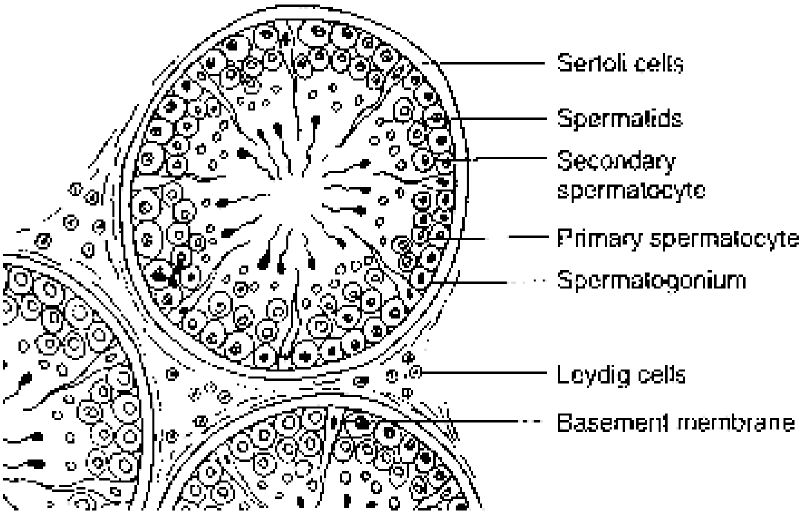


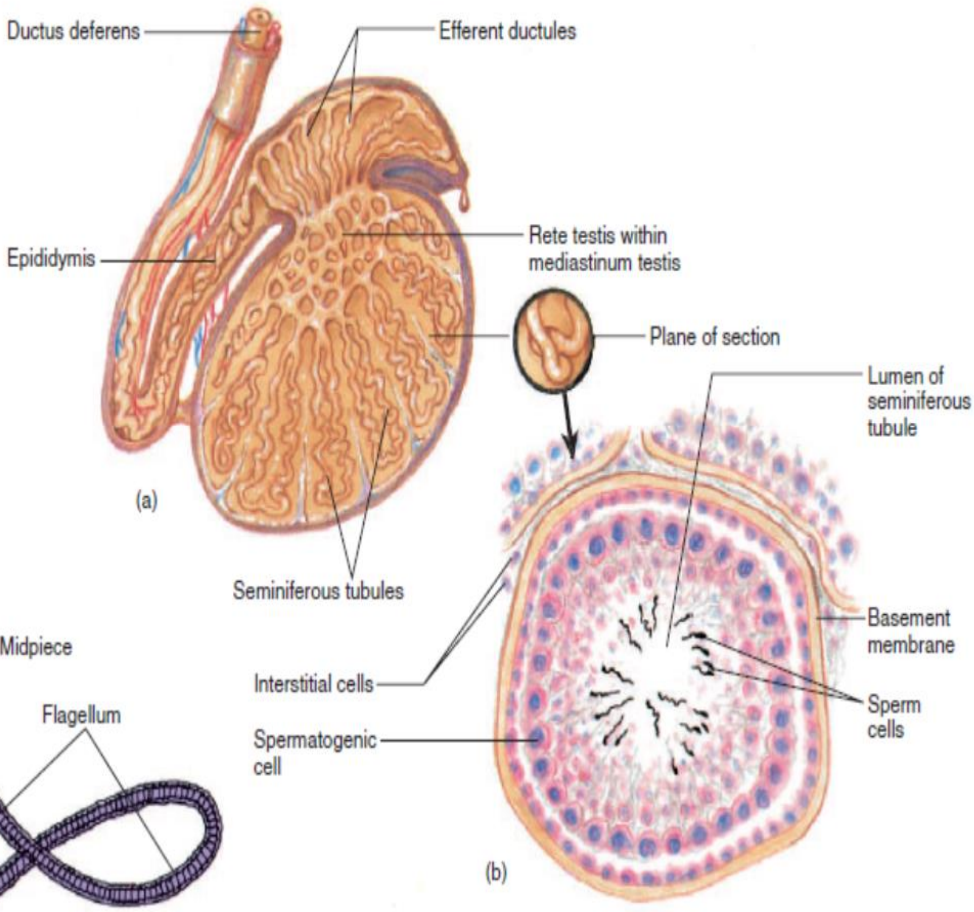
- The germinal cells are present in several layers forming the wall of Seminiferous Tubules.
- Sertoli Cells are supportive in the seminiferous tubules and help in the process of spermatogenesis.
- Spermatogenesis takes place in the seminiferous tubules.
- This includes mitosis and meiosis to form haploid gametes.

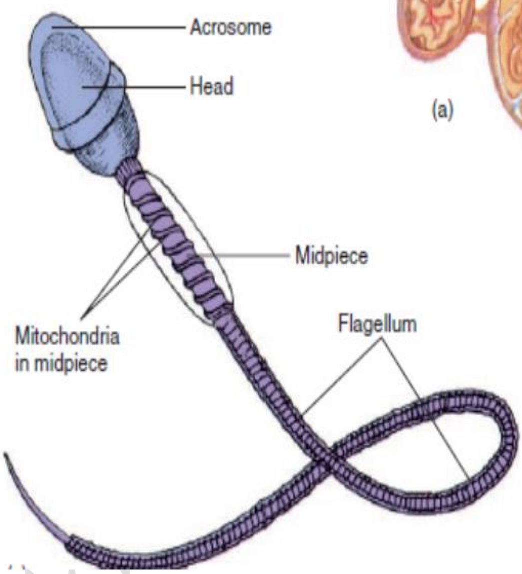


TS of Human Testis

- Spermatogonium passes through Primary spermatocyte, Secondary Spermatocyes, Spermatids, and finally haploid sperms.





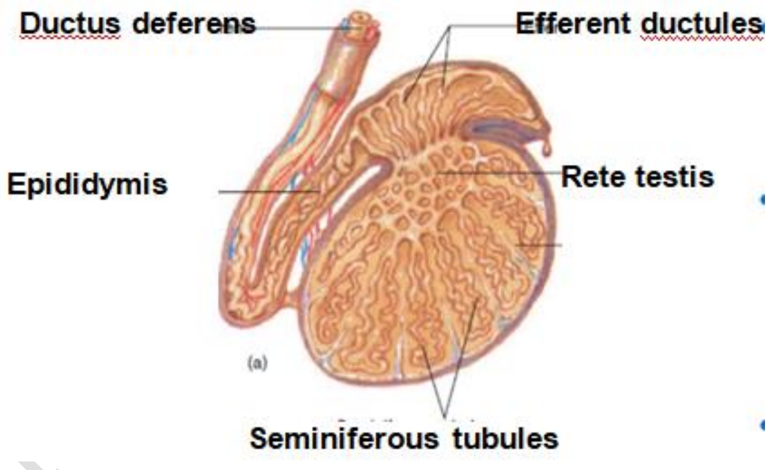


Production of Sperms

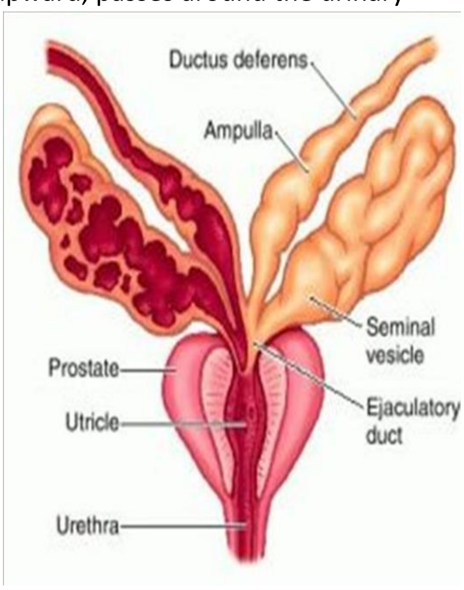
- The paired testes are the male reproductive organs that produce sperms.
- Shortly after birth, the testes descend from the abdominal cavity into the scrotum which hangs between the thighs.
- Testes hang outside the body, the temperature inside the scrotum is about 34° C compared to a 37° C core temperature.
- The lower temperature is necessary for active sperm production and survival.
- Muscles elevate or lower the testes, depending on the outside air temperature.
- Each testis contains over eight hundred tightly coiled seminiferous tubules which produce thousands of sperm each second in healthy young men.
- The walls of the seminiferous tubules are lined with two types of cells:
- Spermatogenic cells, which give rise to sperm, and Sustentacular cells, which nourish the sperm as they form and secrete a fluid and a hormone, inhibin, into the tubules to provide a liquid medium for the sperm.
- Between the seminiferous tubules are clusters of endocrine cells, called Leydig cells, which secrete the male sex hormone, the testosterone.

Transport of Sperms in Man

- A system of tubes carries the sperms from the testes to the penis.
- The seminiferous tubules merge into a network of tiny tubules called the rete testis, which merges into a coiled tube called the epididymis.
- The epididymis has three main functions:
    1. It stores sperms until they mature and ready to be ejaculated
    2. It contains smooth muscle that helps propel the sperm toward the penis by peristaltic contractions
    3. It serves as a duct system for sperm to pass from the testis to the ductus deferens.



- The ductus deferens or sperm duct after leaving the scrotum, continues upward, passes around the urinary bladder and enlarges to form the ampulla.
- The ampulla stores some sperm until they are ejaculated.
- Distal to the ampulla, the ductus deferens becomes the ejaculatory duct.
- The urethra is the final section of the reproductive duct system.



Accessory Glands and their Secretions

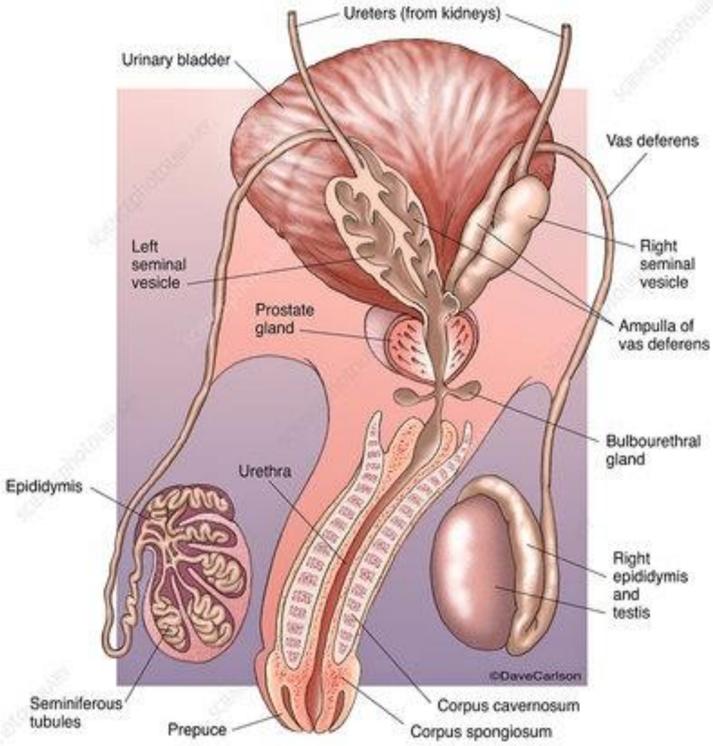
- After the ductus deferens passes around the urinary bladder, several accessory glands add their secretions to the sperm as they are propelled through the ducts.

  These accessory glands are:

  1. Seminal vesicles
  2. Prostate gland, and
  3. Bulbourethral glands

Seminal Vesicles:

- These vesicles are paired secrete water, fructose, prostaglandins, and vitamin C.
- This secretion provides an energy source for the motility of sperms.
- Also helps to neutralize the natural protective acidity of the vagina. (The pH of the vagina is about 3 to 4).
- When vaginal pH increases to about 6 the sperm motility and fertility enhances

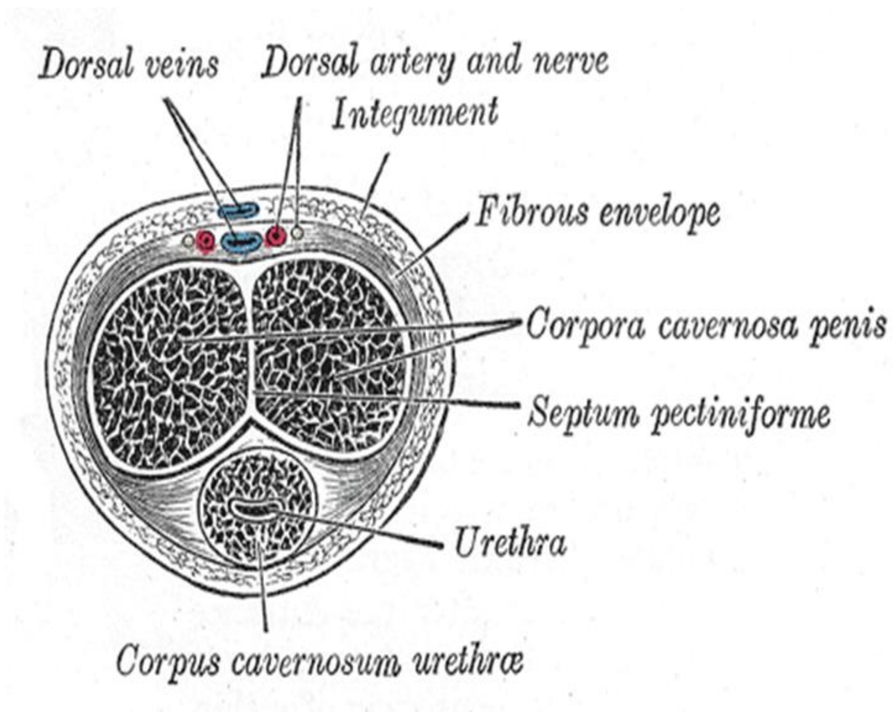


The Prostate Gland

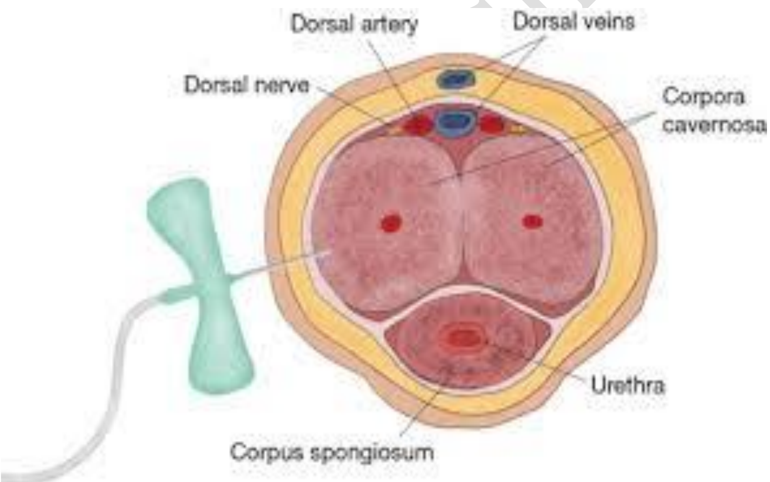
- It is walnut sized gland, located between the bladder and penis.
- It secretes water, enzymes, cholesterol, buffering salts, and phospholipids.

The Bulbourethral Glands:

- The bulbourethral glands (also known as Cowper's glands) are a pair of pea shaped exocrine glands urethra.
- These glands secrete a clear, alkaline fluid that lubricates the urethra to facilitate the ejaculation of semen and lubricates the penis prior to sexual intercourse.
- The penis has two functions. It carries urine through the urethra to the outside during urination, and it transports semen through the urethra during ejaculation.
- In addition to the urethra, the penis contains three cylindrical strands of erectile tissue: two corpora cavernosa and the corpus spongiosum.

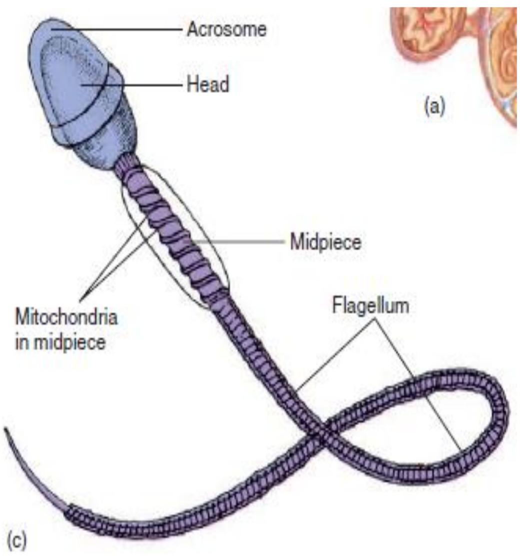


- The corpus spongiosum extends beyond the corpora cavernosa and becomes the expanded tip of the penis called the glans penis.
- The loosely fitting skin of the penis folds forward over the glans to form the prepuce or foreskin.
- Circumcision is the removal of the prepuce for religious or health reasons.
- The fluid that results from the combination of sperm and glandular secretions is semen.
- The average human ejaculation is about 3 to 4 ml of semen and contains 300 to 400 million sperms.
- Today, many circumcisions are performed in the belief that they lessen the likelihood of cancer of the penis.



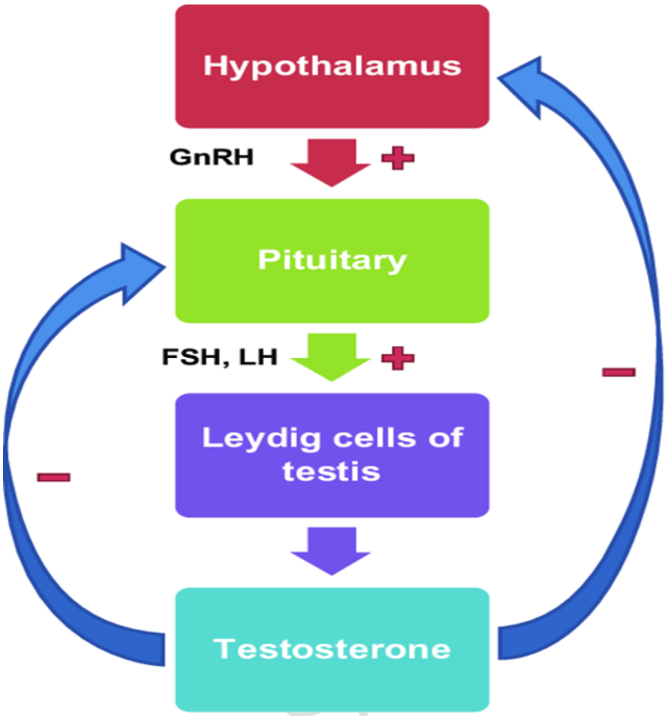
Structure of Human Sperm

- A mature human sperm consists of a head, midpiece, and tail.
- The head is flat, disc shaped 5.1 µm by 3.1 µm and contains the haploid nucleus, which is mostly DNA.
- The acrosome, a cap over most of the head, contains an enzyme called *acrosin* that assists the sperm in penetrating the outer layer surrounding a secondary oocyte.
- The spiral mitochondria in the midpiece supply the ATP necessary for these movements.
- The sperm tail is 50 µm long contains an array of microtubules that bend to produce whip like movements.



Hormonal Control of Male Reproductive Function

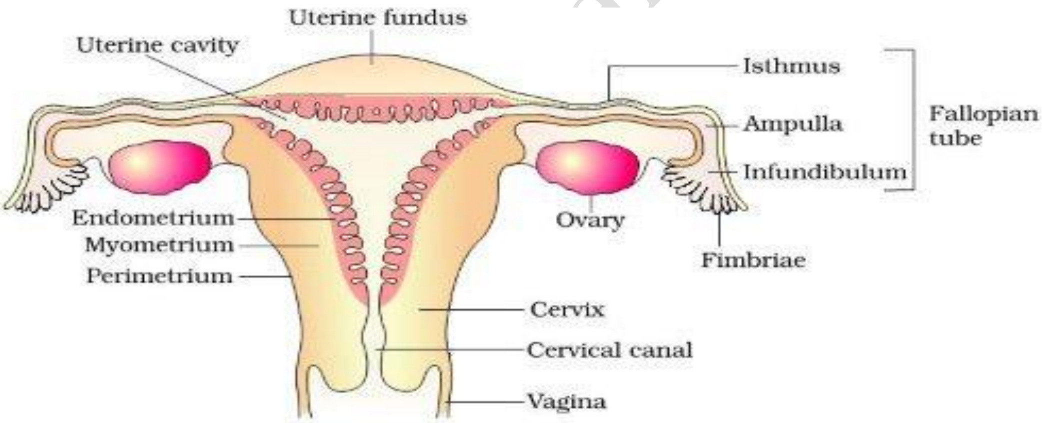
- Before a male can mature and function sexually, special regulatory hormones must come into play.
- Male sex hormones are collectively called androgens.
- The hormones that travel from the brain and pituitary gland to the testes and ovaries are called gonadotropins.
- As previously noted, the interstitial cells (leydig cells) produce the male sex hormone testosterone.
- Figure shows the negative feedback mechanisms that regulate the production and secretion of testosterone, as well as its actions.



- When the level of testosterone in the blood decreases, the hypothalamus is stimulated to secrete GnRH (gonadotropin-releasing hormone).
- GnRH stimulates the secretion of FSH (follicle-stimulating hormone) and LH (luteinizing hormone), also called ICSH (interstitial cell-stimulating hormone), into the bloodstream.
- (FSH and LH were first named for their functions in females, but their molecular structure is exactly the same in males.)
- FSH causes the spermatogenic cells in the seminiferous tubules to initiate spermatogenesis, and LH stimulates the interstitial cells to secrete testosterone.
- The cycle is completed when testosterone inhibits the secretion of LH, and another hormone, inhibin, is secreted.
- Inhibin inhibits the secretion of FSH from the anterior pituitary.
- This cycle maintains a constant rate (homeostasis) of spermatogenesis.

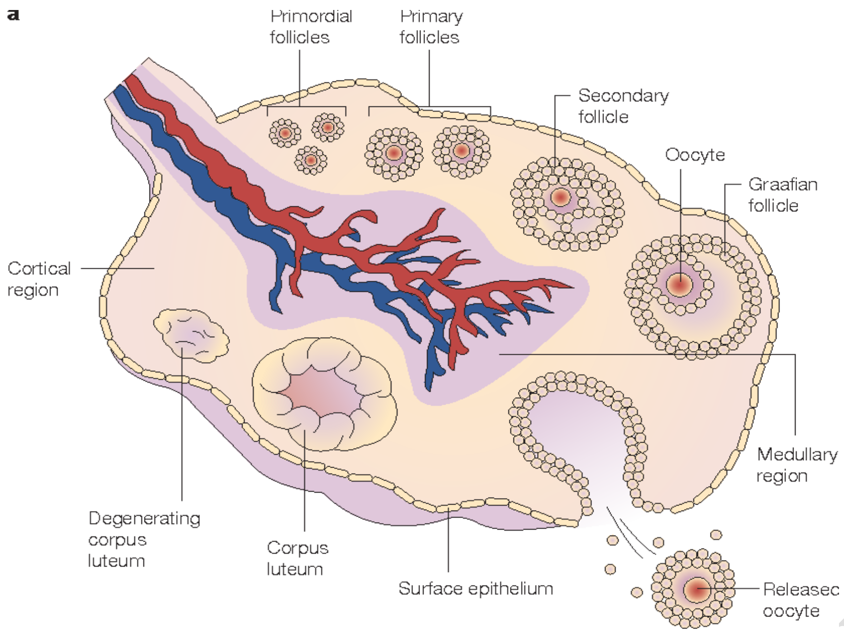
Human Female Reproductive System

- The main external structures of the female reproductive system include:
    - **Labia majora**: enclose and protect the other external reproductive organs.
    - **Labia minora**: They lie just inside the labia majora, and surround the openings to the vagina.
    - **Clitoris:** a small, sensitive protrusion at the point where the two labia minora meet.
        - This is comparable to the penis in males.
        - The clitoris is covered by a fold of skin, called the Hilum.
    - **Vagina:** The vagina is a canal that joins the cervix (the lower part of uterus) to the outside of the body. It also is known as the birth canal.
- In most young women, the vaginal opening is partially covered by a thin membrane, the hymen, which may be ruptured during normal strenuous activities or may be stretched or broken during sexual activity.
- **Uterus:** The uterus is a hollow, pear-shaped organ that is the home to a developing fetus.
- The uterus is divided into two parts: the cervix, which is the lower part that opens into the vagina, and the main body of the uterus is called corpus.
- The corpus can easily expand to hold a developing baby.
- A canal through the cervix allows sperm to enter and menstrual blood to exit.
- **Ovaries**: The ovaries are almond sized, oval-shaped glands that are located on either side of the uterus.
- The ovaries produce eggs and hormones.
- **Fallopian tubes:** These are narrow tubes that are attached to the upper part of the uterus and serve as pathways for the ova (egg cells) to travel from the ovaries to the uterus.
- Fertilization of an egg by a sperm normally occurs in the fallopian tubes.
- The fertilized egg then moves to the uterus, where it implants to the uterine lining.



Histology of Human Ovary

- The ovaries are held in place by ligaments (mesovarium) attached to the uterus through which vessels and nerves pass to the ovary.
- The ovaries have two functions:
    1. Production of ova
    2. Secretion of hormones.
- The surface of the ovary is covered by a single layer of cuboidal epithelium, called germinal epithelium.
- Fibrous connective tissue forms a thin capsule, the tunica albuginea, immediately beneath the epithelium.
- Ovary is divided into an outer cortex and an inner medulla.
- The cortex consists of a very cellular connective tissue stroma in which the ovarian follicles are embedded.
- The medulla is composed of loose connective tissue, which contains blood vessels and nerves.



Ovarian Follicles

- Ovarian follicles consist of one oocyte and surrounding follicular cells.
- Follicular development can be divided into a number of stages.

Primordial follicles

- Primordial follicles are located in the cortex just beneath tunica albuginea. One layer of flattened follicular cells surrounds the oocyte.

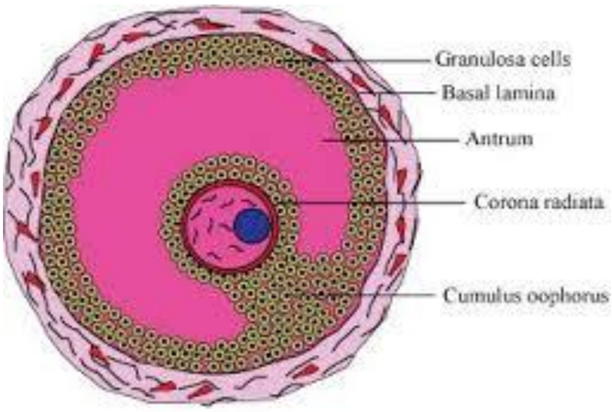
The Primary Follicle

- The primary follicle is the first morphological stage that marks the onset of follicular.
- The previously flattened cell surrounding the oocyte now forms a cuboidal or columnar epithelium surrounding the oocyte.

Secondary follicle

- Small fluid-filled spaces become visible between the granulosa cells as the follicle reaches a diameter of about 400 µm.
- These spaces enlarge and fuse to form the follicular antrum.

- Graafian follicle or mature follicle forms a small "bump" on the surface of the ovary.
- The Graafian follicle finally ruptures and the oocyte is released from the ovary.



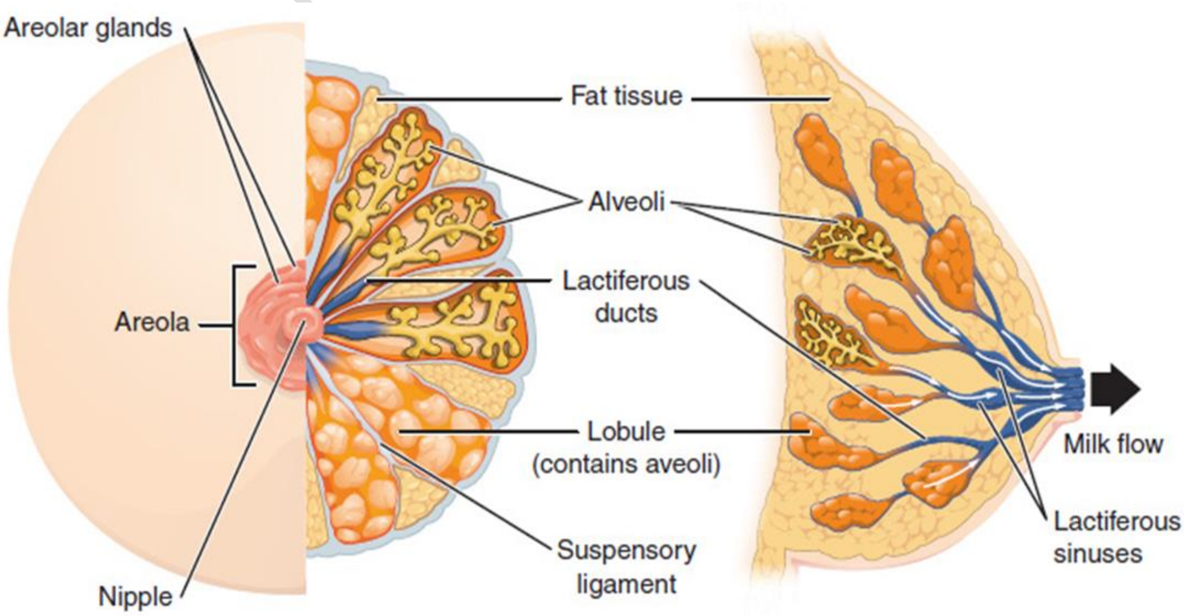
Structure of the Graafian follicle

- After ovulation, the lining of the follicle grows inward, forming the corpus luteum ("yellow body"), which serves as a temporary endocrine tissue and continues to secrete the female sex hormones estrogen and progesterone**.**

Mammary Glands and Production of Milk

The Mammary Glands

- Mammary Glands are modified sweat glands.
- Mammary Glands produce and secrete milk.
- They contain varying amounts of adipose tissue.
- The amount of adipose tissue determines the size of the breasts, but the amount of mammary tissue does not vary widely from one woman to another.
- The basic components of the mammary gland are the alveoli (hollow cavities, a few millimetres large) lined with milk-secreting cuboidal cells.
- These alveoli join up to form groups known as lobules, and each lobule has a lactiferous duct that drains into openings in the nipple.



- The lobules group together to form a lobe.
- There are 15 -20 lobes in each Mammary Glands.

Reproductive Cycles in Mammals

- Reproductive Cycle is a set of physiologic changes that recur regularly in the reproductive organs of female mammals.
- There are two types of Reproductive Cycles found in mammals:
    - Estrous Cycle and
    - Menstrual Cycle

Estrous Cycle:

- In animals with estrous cycles, the female is sexually receptive ("in heat") only during the estrus phase of the cycle.
- In animals with estrous cycles, the uterus reabsorbs the thickened lining of the endometrium if conception does not occur.
- The frequency and length of the estrus phase varies.
- For example, In cow the estrus phase lasts avg. 24 hours in 21 days cycle.
- In dogs, the estrus cycle typically occurs twice a year with:
    - Proestrus lasts 4-20 days
    - Estrus 4-13 days
    - Metestrus 60-90 days
    - Diestrus lasts 90-150 days

- In rats and mice the estrous cycle lasts four days and is characterized as: proestrus, estrus, metestrus and diestrus. The estrous period is about 12 hours.

Menstrual Cycle

- Adult female mammals without estrous cycle have the Menstrual Cycle.
- In these mammals uterus sheds the thickened lining of the endometrium along with blood and mucosal tissue through the vaginal opening if conception does not occur.
- In adult human females the Menstrual Cycle is of 28 days and the menstrual period averages 5 days.
- Menstruation in mammals other than human occurs in primates (apes and monkeys), chimpanzee and gibbon.
- Ape species include humans, gorillas, chimpanzees, gibbons.
- Monkey species include baboons, macaques, and marmosets.

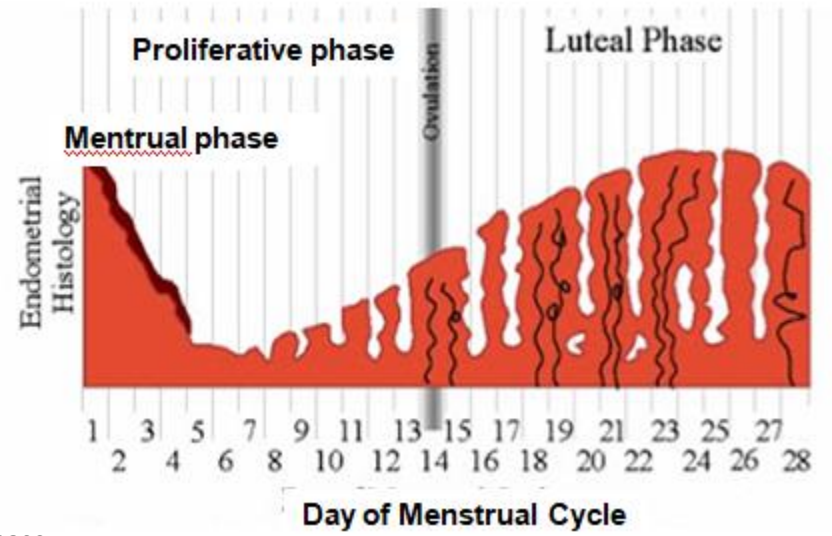
Human Female Reproductive Cycle

- Human Female Reproductive Cycle is a rhythmical series of physiological changes that occur in fertile woman.
- Necessary for reproduction.
- Average length of the cycle is 28 days.

Menstual cycle

Menstrual Cycle can be divided into three phases:

1. Menstrual phase
2. Proliferative and
3. Luteal/Secretory phase



The menstrual phase

- It is the first stage of the menstrual cycle that lasts for 4-5 days.
- This phase starts when an egg from the previous cycle is not fertilized, because pregnancy has not taken place.

The proliferative phase

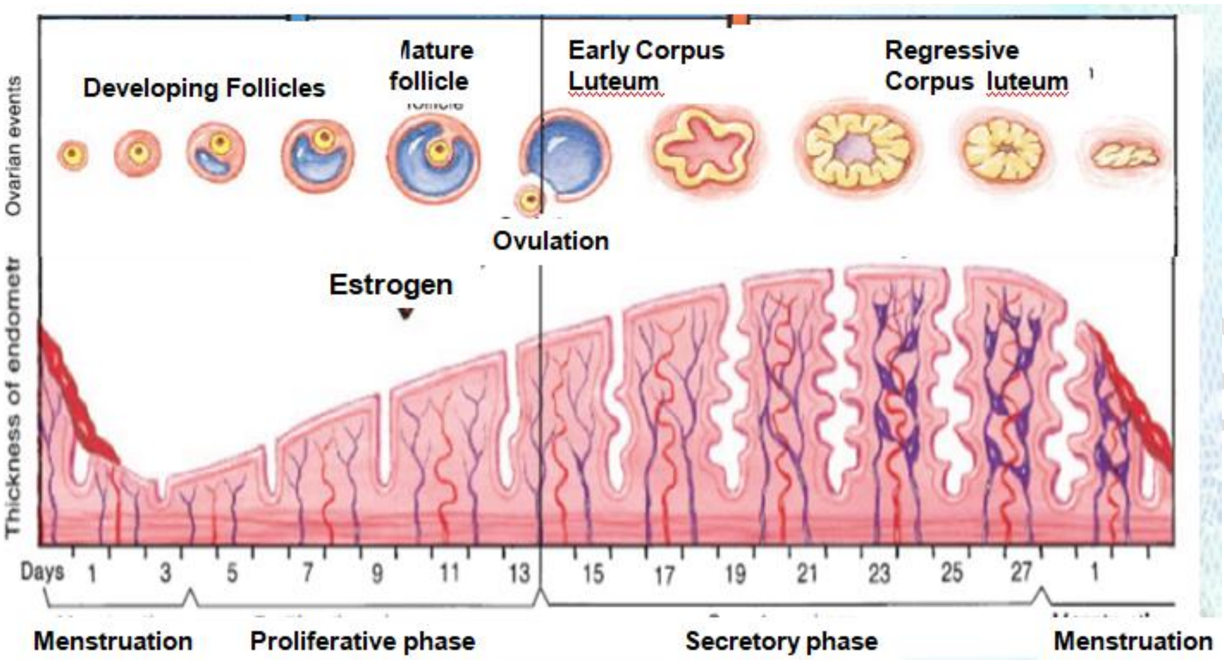
- It is the second phase of the cycle when the lining of the uterus grows, or proliferate.
- It lasts for 8 to 9 days.

The luteal phase

- It begins after ovulation.
- It lasts about 14 days (unless fertilization occurs) and ends just before menstrual period.

Hormonal Control of Menstrual Cycle

- The male is continuously fertile from puberty to old age, and throughout that period, sex hormones are continuously secreted.
- The female, however, is fertile only during a few days each month.
- This pattern is related to the cyclical release of hormones from the ovary.
- The cyclical production of ovarian hormones regulates the menstrual cycle, as well as the ovarian cycle, during which the oocytes mature and ovulation occurs.
- The developments of the oocyte in one of the immature ovarian follicles produce estrogen, causing proliferation of the endometrium.



- The elevated estrogen level about midway in the cycle triggers the maturing follicle to enlarge rapidly and release the secondary oocyte (ovulation).
- The ruptured follicle becomes another endocrine tissue, the corpus luteum.
- The Corpus Luteum secretes progesterone, which act to complete the development of the endometrium and maintain it for 10 to 14 days. (Luteal Phase)
- If the oocyte is not fertilized, the Corpus Luteum disintegrates into a corpus albicans, and the secretion of estrogen and progesterone cease.
- Without estrogen and progesterone, the endometrium breaks down, and menstruation occurs.

- The controlling center for ovulation and menstruation is the hypothalamus.
- The hypothalamus releases, on a regular cycle, GnRH, which stimulates the anterior lobe of the pituitary gland to secrete follicle stimulating hormone (FSH) and luteinizing hormone (LH).
- The FSH brings about the maturation of oocyte up to its the Graafian follicle.
- The elevated estrogen level about midway in the cycle triggers the anterior pituitary to secrete another hormone LH, which causes the mature follicle to enlarge rapidly to form Graafian follicle.
- The growing follicles produce estrogen, causing a buildup and proliferation of the endometrium, as well as the inhibition of FSH production.
- The increasing level of LH and the decreasing level of FSH bring about the release of oocyte from the Graafian follicle (ovulation).
- LH also causes the ruptured follicle to become another endocrine tissue, the corpus luteum.
- The corpus luteum starts producing another hormone, progesteron.
- As long as the progesteron is released the endometrium is intact. (this is normally for 8 to 9 days).
- The immediate breakdown of copus luteum stops the production of progesterone.
- This causes the breakdown of endometrium and the M phase starts.
- The decreasing level of progesteron renews active secretion of FSH, which stimulates the development of another follicle, and the monthly cycle begins again.
- When a female reaches 45 to 55 years of age, the ovaries lose their sensitivity to FSH and LH,
- They stop making normal amounts of estrogen and progesterone and the monthly cycle ceases to occur permanantly
- This condition is called Menopause.

Summary of Menstrual Cycle

- The important events of the menstrual cycle, are ovulation and menstruation
- Endocrine regulation of female reproduction involves the hypothalamus, pituitary gland, and ovaries.
- The first day of the menstrual cycle is marked by the beginning of menstrual bleeding.

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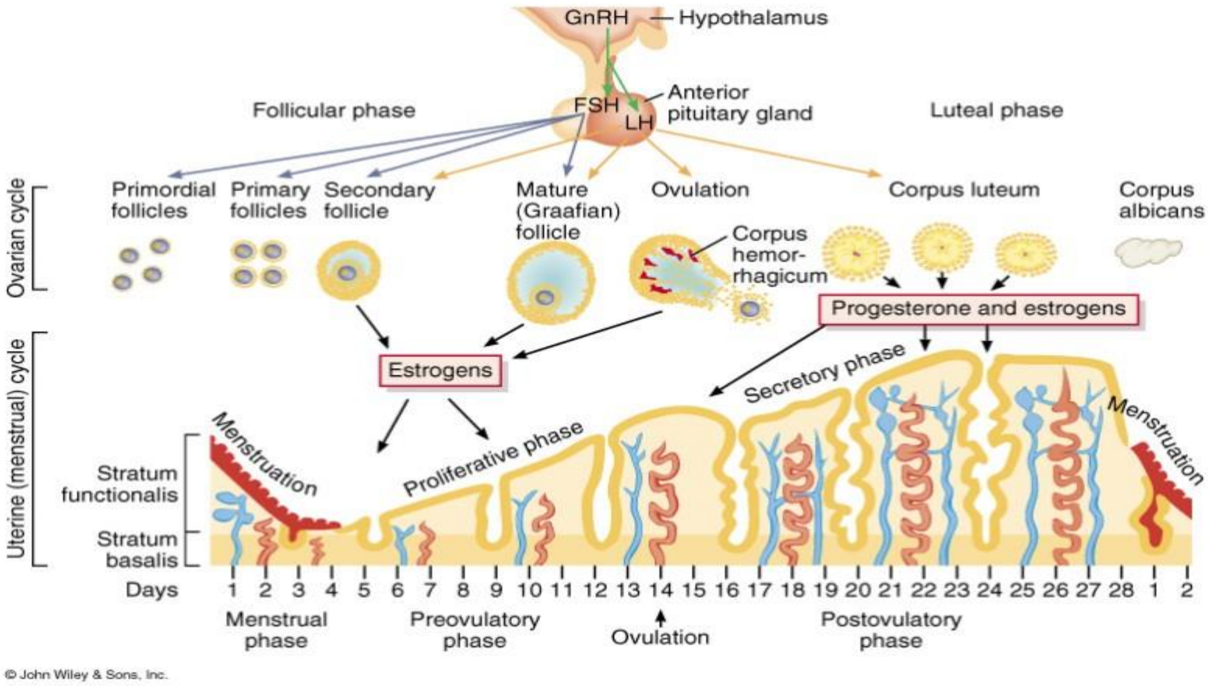


- Ovulation occurs at about day 14 in a typical 28-day menstrual cycle.
- During the preovulatory phase, gonadotropin-releasing hormone (GnRH) from the hypothalamus stimulates the anterior lobe of the pituitary to secrete follicle-stimulating hormone (FSH) and luteinizing hormone (LH).
- FSH stimulates follicle development and stimulates the granulosa cells to produce estrogen.
- LH stimulates theca cells to multiply and produce androgens, which are converted to estrogen.
- Estrogen is responsible for primary and secondary female sex characteristics and stimulates development of the endometrium.
- After the first week, only one follicle continues to develop.
- Although at relatively low concentration, estrogen inhibits FSH secretion by negative feedback.
- Granulosa cells produce inhibin, which also inhibits FSH secretion
- During the late preovulatory phase, estrogen concentration peaks and through positive feedback signals the anterior pituitary to secrete LH.
- LH stimulates final maturation of the follicle and stimulates ovulation.
- During the postovulatory phase, LH promotes development of the corpus luteum.
- The corpus luteum secretes rogesterone and estrogen, which stimulate final preparation of the uterus for pregnancy.
- During the postovulatory phase, progesterone, along with estrogen, inhibits secretion of GnRH, FSH, and LH.
- If fertilization does not occur, the corpus luteum degenerates, concentrations of estrogen and progesterone in the blood fall, and menstruation occurs.

Hormonal Regulation in Pregnant Females

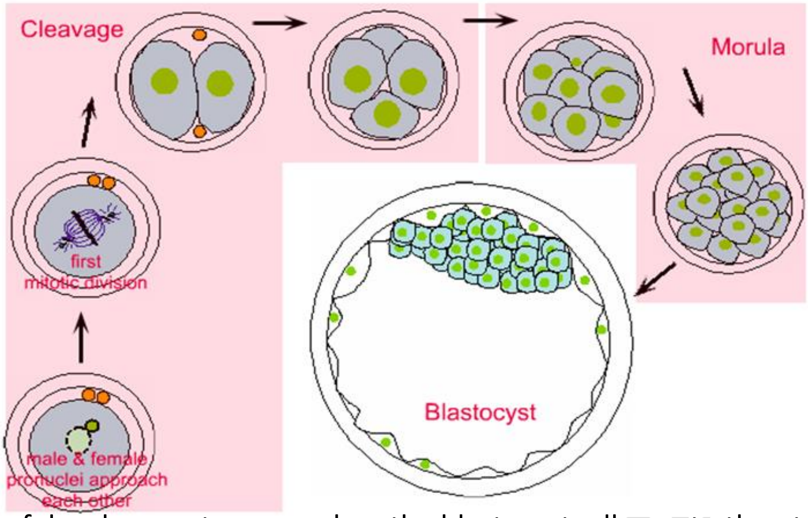
- Pregnancy/Gestation is the time during which one or more offspring develops inside a woman.
- Pregnancy sets into motion a new series of physiological events.
- In pregnancy ovaries are directly affected.
- As the embryo develops, the placenta releases a hormone, human chorionic gonadotropin (hCG), which keeps the corpus luteum from disintegrating.
- The progesterone is necessary to maintain the uterine lining.
- After a time, the placenta takes over progesterone production, and the corpus luteum degenerates.
- By the end of two weeks following implantation, the concentration of hCG increases in the female's blood as well as in urine.
- hCG immunological test can check for pregnancy.
- As the embryo develops, other hormones such as prolactin and oxytocin are secreted.
- Prolactin induces the mammary glands to secrete and eject milk after childbirth.
- Oxytocin stimulates the uterine contractions during childbirth.
- It is also important for lactation, and certain aspects of human behavior.

Embryonic Development in Human

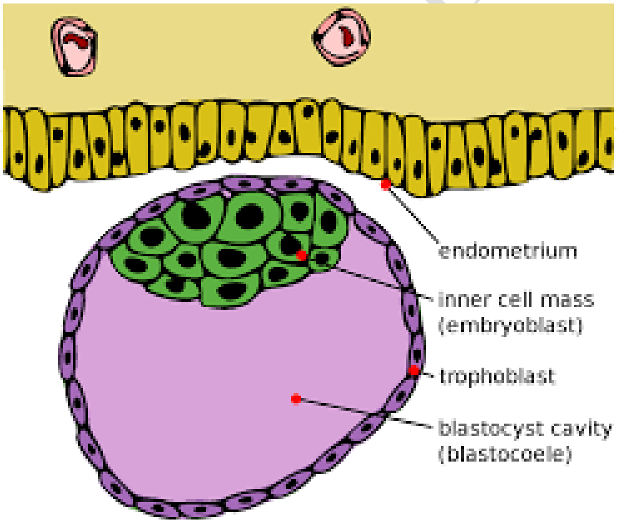
- This topic covers the main event in reproduction—the nine month pregnancy/gestation period, during which time the woman carries, nourishes, and protects the embryo that grows to a full-term baby.
- The development of a human being can be divided into: prenatal (before birth) and postnatal (after birth) development.
- During the prenatal period, the developing individual takes its start becomes a ball of cells called a morula, and eventually becomes a blastocyst that implants in the endometrium.
- From two weeks after fertilization until the end of the eighth week of its existence, the individual is called an embryo.
- From nine weeks until birth, it is a fetus.
- During or after birth, it is called a newborn baby, or neonate.
- Pregnancy is arbitrarily divided into three-month periods called trimesters.
- The first trimester begins at fertilization, and during this time most of the organs are formed.
- The next two trimesters are mainly periods of growth for the fetus.

Prenatal Development (First Trimester)

- After fertilization, usually in the upper third of the uterine tube, the zygote goes through several cleavages as it moves down the tube.
- It eventually becomes a solid ball of cells called a morula, and by the fourth day, it develops into a 50 to120-cell blastula stage called a blastocyst.



- The next stage of development occurs when the blastocyst adheres to the uterine wall and implants.
- During implantation, the outer cells of the blastocyst, called the trophoblast, invade the endometrium.



- Implantation is usually completed 11 to 12 days after fertilization; from then on, the female is considered to be pregnant.
- One of the unique features of mammalian development is that most of the cells of the early embryo make no contribution to the embryo's body, giving rise instead to supportive and protective membranes.
- Only the inner cell mass gives rise to the embryonic body.
- Eventually, these cells arrange in a flat sheet that undergoes a gastrulation similar to that of reptiles and birds.
- Once gastrulation is completed, the rest of the first trimester is devoted to organogenesis and growth.
- Regulatory events and inductive-tissue interactions shape most of the organ systems.
- By the middle of the first trimester, all of the major body systems begin to develop.

Prenatal Development (Second Trimester)

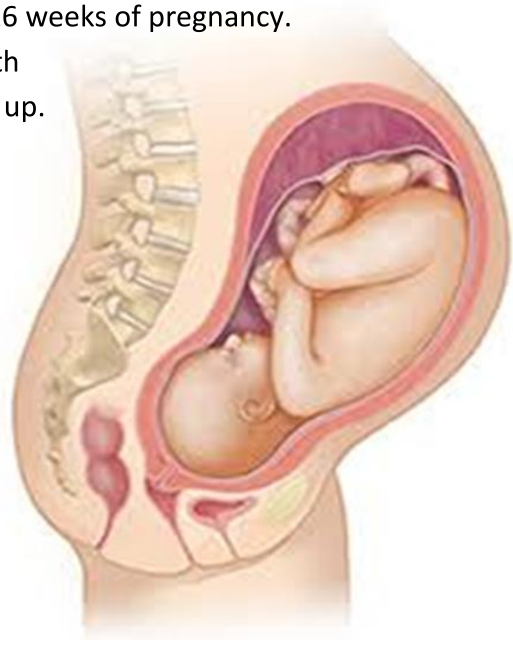
The Second Trimester

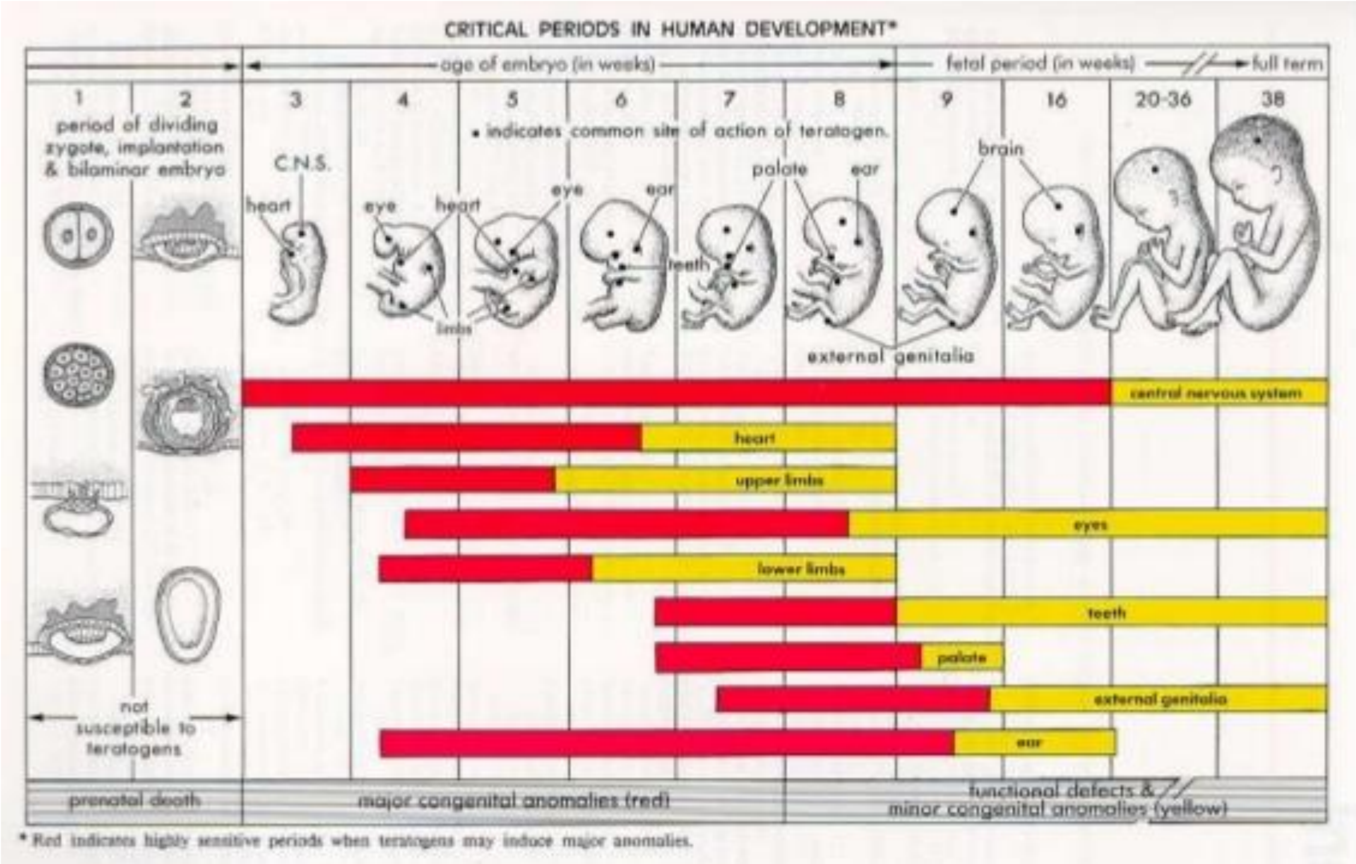
- In the second trimester (4th to 6th month), fetal growth is spectacular.
- By now, the pregnant mother is aware of fetal movements.
- The heartbeat can be heard with a stethoscope.
- During the sixth month, the upper and lower eyelids separate, and the eyelashes appear.
- During this period, the bones begin to ossify.

- During the final weeks of second trimester, major organs — such as the liver and pancreas — become clear.
- By the end of 6th month of pregnancy, the fetus is about 10 to 11 inches long and weighs about 1 pound.

Prenatal Development (Third Trimester)

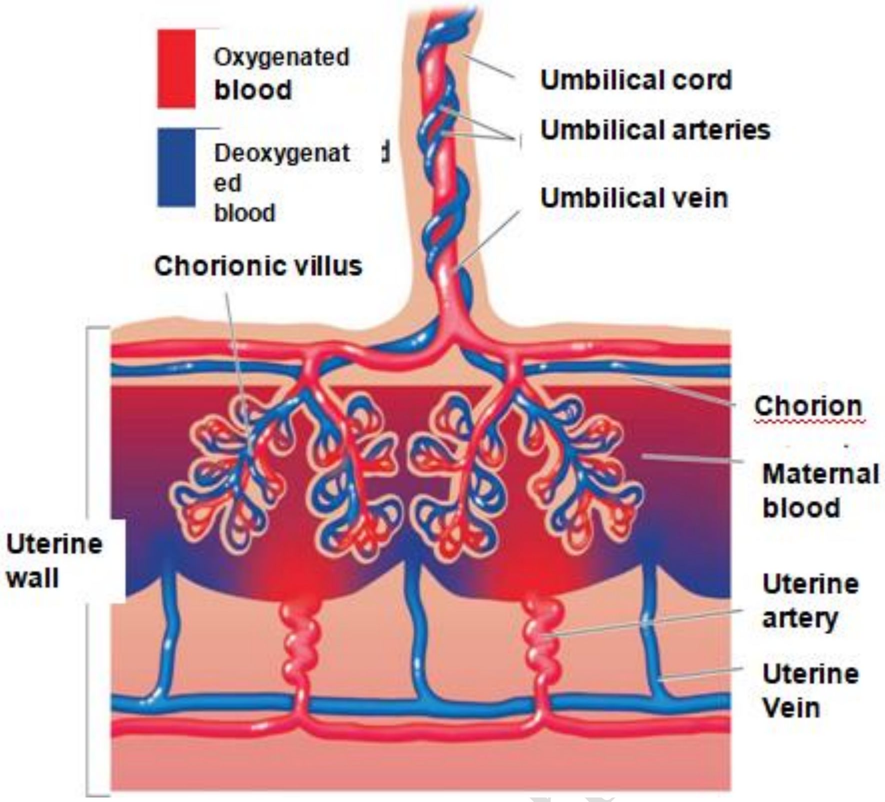
- The third trimester extends from the seventh month until birth.
- During this time, the fetus has developed sufficiently (with respect to the circulatory and respiratory systems) to potentially survive if born prematurely.
- Surfactant is a liquid made by the lungs that keeps the airways (alveoli) open.
- This liquid makes it possible for babies to breathe in air after delivery.
- An unborn baby starts to make surfactant at about 26 weeks of pregnancy.
- Fetus prepares for birth towards the end of 9th month
- The fetus is positioned head down with limbs curled up.
- During the last month, fetal weight doubles.





Placenta: Structure and Function

- The placenta is the organ that sustains the embryo and fetus throughout the pregnancy and through which gases are exchanged, nutrients are supplied and wastes are removed from the fetal systems to the maternal end.
- The tiny fingerlike projections are sent out from the blastocyst during implantation develop into numerous chorionic villi, which contain embryonic blood vessels.
- These blood vessels do not merge with those of the mother; the two bloodstreams remain separate throughout the pregnancy



- Placenta is a feto-maternal organ
- It has two components
- Fetal part develops from the chorionic sac.
- Maternal part, derived from endometrium.
- The placenta and the umbilical cord is the system for transporting substances between the mother and the fetus.
- Branches of the mother's arteries in the wall of her uterus open into pools near the chorionic villi.
- Oxygen and nutrients from the mother's blood diffuse into the fetal capillaries of the placenta.

Functions of the placenta

- Gas exchange, nutrition, hormone secretion, Excretion and fetal protection.
- Nutrient and drug transfer across the placenta are by passive diffusion, facilitated diffusion, active transport, and pinocytosis.
- The umbilical cord connects the placenta to the abdomen of the fetus.
- Two fetal umbilical arteries and one fetal umbilical vein spiral about each other in the umbilical cord.
- Oxygen and nutrients from the mother's blood diffuse into the fetal capillaries of the placenta.
- The fetal capillaries lead into the umbilical vein, which is enclosed within the umbilical cord.
- From here, the fresh blood circulates through the fetus's body.

Childbirth

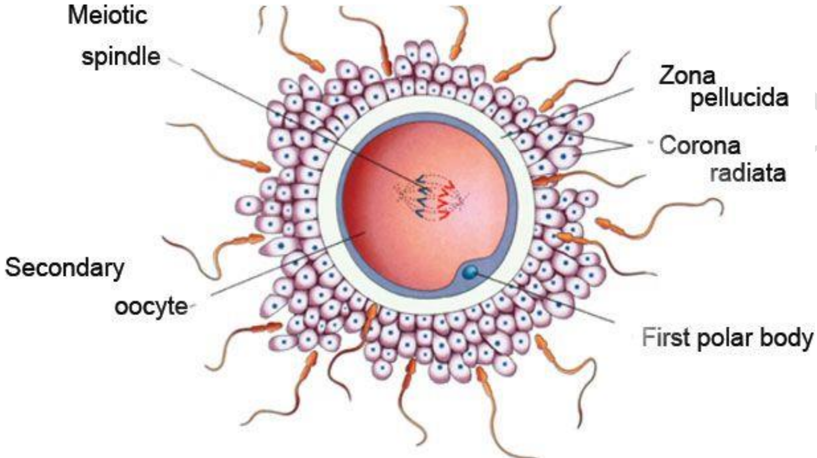
- About 266 days after fertilization, or 280 days from the beginning of the last menstrual period, the human baby is born.
- The birth process is called parturition.
- During parturition, the mother's uterine muscles begin to contract, and the cervix begins to dilate, or open.
- The hormone relaxin, produced by the ovaries and placenta, causes the mother's pelvic bones to slightly separate so that the baby can pass through the birth canal.
- Changing hormone levels initiate parturition.
- When it is time for the baby to be born, its pituitary gland secretes adrenocorticotropic hormone (ACTH), which stimulates the adrenal glands to secrete steroids.
- These steroids stimulate the placenta to produce prostaglandins and pituitary to produce oxytocin.
- These hormones cause the uterus to begin powerful muscular contractions.
- The contractions build in length and increase in frequency over a period that usually lasts from 2 to 18 hours.
- During that time, the cervix becomes fully dilated, and the amniotic sac ruptures.
- Usually within an hour of these events, the baby is expelled from the uterus.
- After the baby emerges, uterine contractions continue to expel the afterbirth (Placenta and umbilical cord).
- The umbilical cord is severed, and the newborn gets on the outside world.
- In mammals other than humans, the female bites through the cord to sever it.

Milk Production and Lactation

- Lactation includes both milk secretions (production) by the mammary glands and milk release from the breasts.
- During pregnancy, the breasts enlarge in response to increasing levels of the hormone prolactin.
- Before birth, placental secretions of estrogen and progesterone inhibit milk secretion from the breasts.
- After the placenta has been expelled from the uterus, the concentrations of estrogen and progesterone drop, and the breasts begin to produce copious amounts of milk.
- The mother's breasts do not actually release milk until one to three days after the baby is born.
- During these first days, the suckling baby receives colostrum, a high-protein fluid present in the breast at birth.
- Colostrum contains an abundance of maternal antibodies and thus helps strengthen the baby's immune system.
- It also functions as a laxative, removing fetal wastes, called meconium, retained in the intestines.
- After about three days, the prolactin secreted from the pituitary stimulates milk production.
- The newborn's suckling stimulates the pituitary to release oxytocin as well as prolactin.
- Prolactin triggers milk release from the mammary glands.

Process of Fertilization

- Fertilization involves four events:
  - i) The sperm contacts the egg and recognition occurs.
  - ii) The sperm or sperm nucleus enters the egg.
  - (iii) The egg becomes activated, and certain developmental changes begin.
  - (iv) The sperm and egg nuclei fuse.
- An egg is surrounded by a plasma membrane and by one or more external coverings that are important in fertilization.
- For example, a mammalian egg is enclosed by a thick, noncellular, zona pellucida, which is surrounded by a layer of granulosa cells derived from the follicle in which the egg develops.



- Before fertilization the mammalian sperm undergoes capacitation, a maturation process in the in the female reproductive tract.
- During capacitation, the sperms become increasingly motile and capable of undergoing an acrosome reaction when they encounter an egg.

Sperm Entry

- The plasma membrane of the egg is covered with microvilli, which elongate to surround the head of the sperm.
- As they do so, the plasma membranes of sperm and egg fuse and a fertilization cone is formed that contracts to draw the sperm into the egg.

Fertilization activates the egg

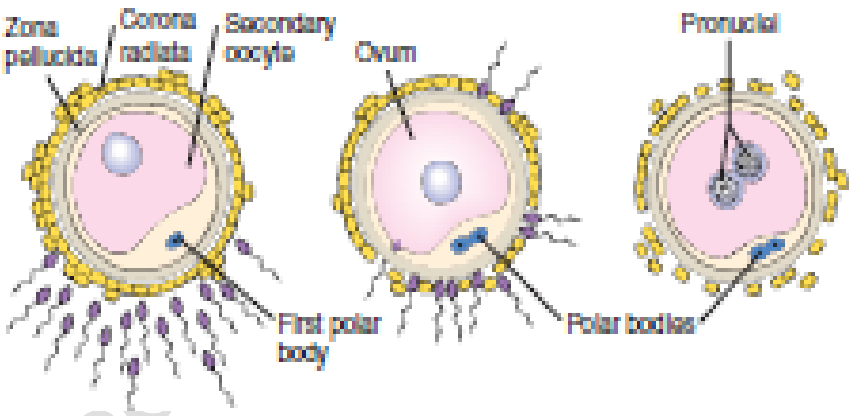
- Release of calcium ions into the egg cytoplasm triggers the activation program, a series of metabolic changes within the egg.
- Aerobic respiration increases, this causes a burst of protein synthesis after sperm entry.
- In addition, the egg nucleus is stimulated to complete meiosis.
- The egg, which is actually a secondary oocyte, arrested early in the second meiotic division.

Sperm and egg pronuclei fuse, restoring the diploid state.

- After the sperm nucleus enters the egg, it swells and forms the male pronucleus.
- The nucleus formed during completion of meiosis in the egg becomes the female pronucleus
- The haploid male and female pronuclei then fuse to form the diploid nucleus of the zygote, and DNA synthesis occurs in preparation for the first cell division.

Fertilization and Implantation

- Fertilization is the fusion of sperm and egg.
- Fertilization and the subsequent establishment of pregnancy together are referred to as conception.
- After ejaculation into the female reproductive tract, sperm remain alive and retain their ability to fertilize an ovum for an estimated 48 to 72 hours.
- The ovum remains fertile for 12 to 24 hours after ovulation.
- Therefore, in a very regular 28-day menstrual cycle, sexual intercourse at mid cycle is most likely to result in fertilization.
- When conditions in the vagina and cervix are favorable, sperm arrive at the site of fertilization, the upper oviduct, within 5 minutes after ejaculation.
- At the time of ovulation, when estrogen concentration is high, the cervical mucus has a thin consistency that permits passage of sperm from the vagina into the uterus.
- After ovulation, when progesterone concentration rises, the cervical mucus becomes thick and sticky,
- This blocks the entrance of sperm.
- Once sperm enter the uterus, contractions of the uterine wall help transport them.
- These contractions are induced, in part, by prostaglandins in the semen.
- The sperm’s own motility is important, especially in approaching and fertilizing the ovum.



- When a sperm encounters an egg, openings develop in the sperm acrosome, exposing enzymes that digest a path through the zona pellucida surrounding the secondary oocyte.
- As soon as one sperm enters the secondary oocyte, changes occur that prevent the entrance of other sperm.
- As the fertilizing sperm enters, it usually loses its flagellum.
- Sperm entry stimulates the secondary oocyte to complete its second meiotic division.
- The head of the haploid sperm then swells to form the male pronucleus and fuses with the female pronucleus to form the diploid nucleus of the zygote. The process of fertilization is described in m

Cleavage and Egg Types

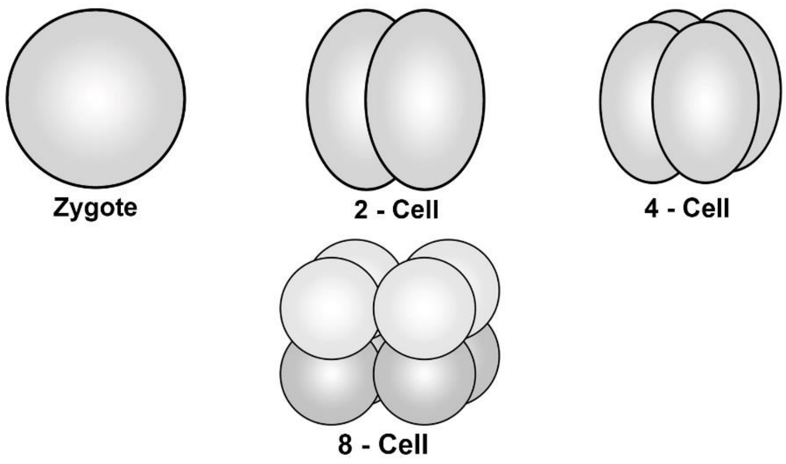
- The zygote formed as a result of fertilization is totipotent, i.e. it gives rise to all the cell types of the new individual.
- Because the ovum is very large compared with the sperm, the bulk of the zygote cytoplasm and organelles comes from the ovum.
- However, the sperm and ovum usually contribute equal numbers of chromosomes.
- Shortly after fertilization, the zygote undergoes cleavage, a series of rapid mitotic divisions with no period of growth during each cell cycle.
- For this reason, although the cell number increases, the embryo does not increase in size.
- The zygote initially divides to form a 2, to 4 , 4 to 8 celled embryo.

EggTypes

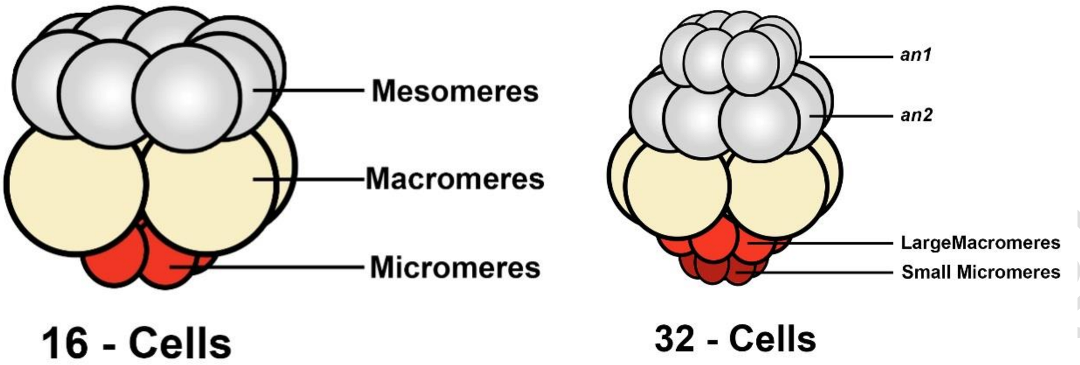
- On the basis of the amount of yolk, eggs are grouped into three types:
  1. **Alecithal Egg**: When the egg contains no yolk. Example eutherian mammals.
  2. **Microlecithal Egg:** When the egg contain small or negligible amount of yolk. Example, Amphioxus, Tunicates
  3. **Mesolecithal egg:** When the amount of yolk present is moderate and is not high. Example Dipnoi, Petromyzon, and amphibians.
  4. **Macrolecithal Egg:** when the egg contains large amount of yolk. Such eggs are also called megalecithal or Polylecithal Example, Reptiles, Birds, Prototheria (Monotremata) Egg laying mammals.
- On the Basis of the distribution of yolk, Eggs may be
  - **Isolecithal or Homolecithal**
    - Yolk is uniformly distributed throughout the ooplasm: Example: Echinoderms, Amphioxus, mammals. In this type of eggs, very little amount of yolk is present.
  - **Telolecithal Eggs**
    - Eggs containing moderate or large quantity of yolk and the distribution are not uniform. Yolk is concentrated more towards the vegetal pole.

Echinoderm Embryology

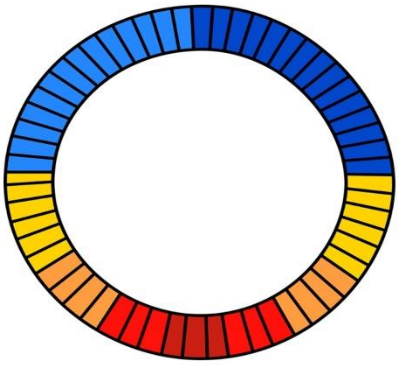
- Echinoderms (Sea Urchin) exhibit radial holoblastic cleavage.
- The first and second clevages are both meridional and at right angles to each other.
- It means the cleavage furrow pass through the animal and vegetal poles.
- The third cleavage is at right angles to the first two, dividing the embryo into 8 cells.



- The vegetal tier, however, undergoes unequal equatorial cleavage to produce four large cells, the macromeres and micromeres at the vegetal pole.
- As the 16-cell embryo cleave, the 8 mesomeres divide to produce two ‘animal tiers’ an_1 and an_2, one above the other.
- The macromeres divide meridionally, forming a tier of 8 cells below an_2.



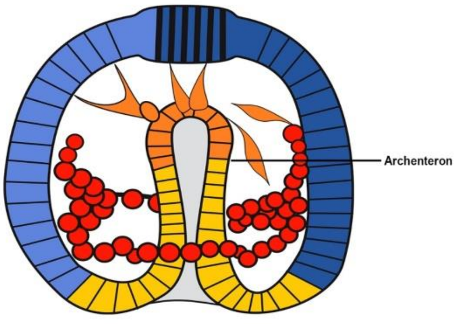
- The 3rd cleavage also separates the four animal and vegetal tiers from each other.
- The 4th cleavage is very different from the first three. The four cells of the animal tier divide meridionally into 8 blastomeres. These cells are called mesomeres.
- The micromeres also divide producing a small cluster beneath the larger tier.
- At the cleavage furrows of the 6th division are equatorial, and the 7th division is meridional, producing a 128- blatula.
- At this stage the cells form a hollow sphere surrounding the central cavity, blastocoel.
- All the cells at stage are of same size and tightly united.



Hatched blastula

- The cells of blastula continue to divide forming one -cell- layer thick thinning out as it expands.
- After 9 or 10 cell division when the synchrony of cell division ends the non dividing cells develop cilia on their outer surfaces.
- The ciliated blastula then begins to rotate within the fertilization envelope.
- Soon after the cells at the vegetal pole begins to thicken forming a vegetal plate.
- The cells of animal half synthesize and secrete a hatching enzyme that digests fertilization envelope
- The embryo is now a free swimming hatched larva.

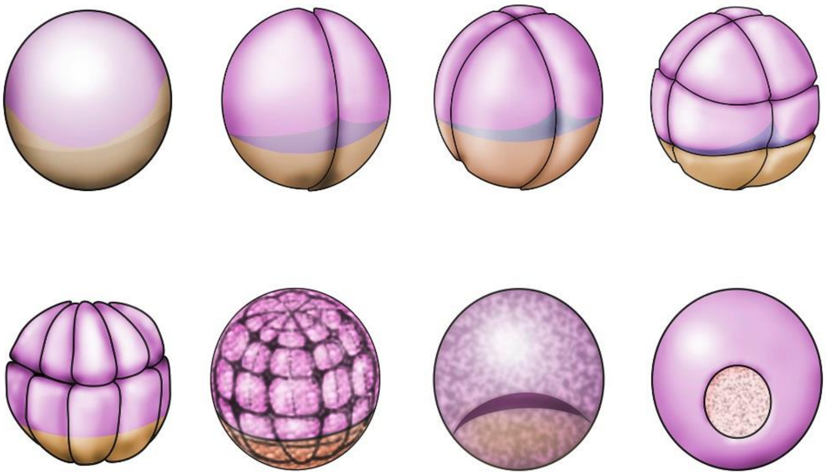
- Sea urchin gastrulation begins with the ingression of primary mesenchyme cells from the vegetal pole.
- Following ingression the vegetal plate invaginates to form a stout cylinder called archenteron.
- This stage is the gastrula which then develops into Pluteus larva.



Late Gastrula

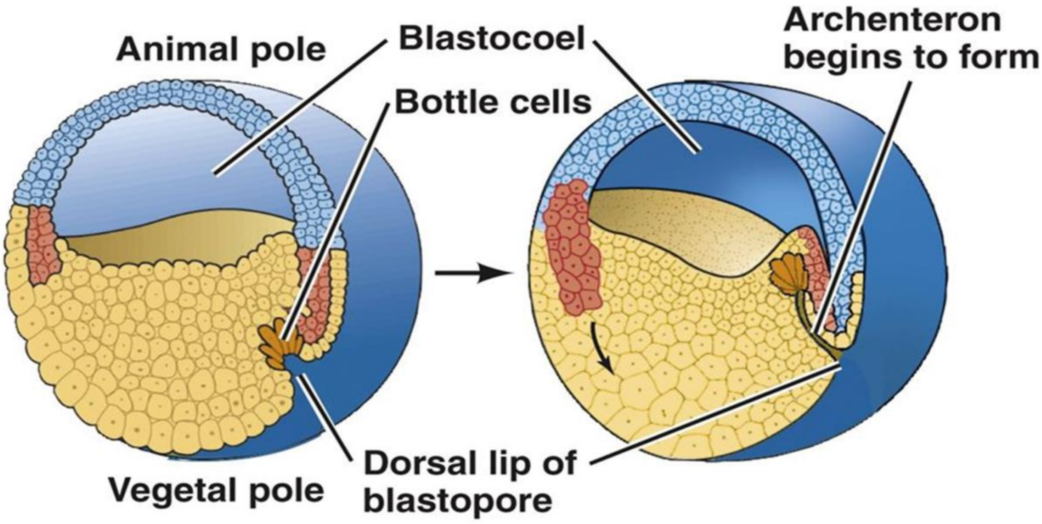
Amphibian Embryology

- Cleavage in amphibians is radially symmetrical and holoblastic.
- The amphibian egg, contains much more yolk which is concentrated in the vegetal hemisphere.
- Here yolk is an obstruction to cleavage.
- The first division begins at the animal pole and slowly extends down into the vegetal region.



- The second cleavage is at right angles to the first one and the third cleavage is towards the animal hemisphere as expected, is equatorial.
- It divides the frog embryo into 8 cells, four small animal blastomeres (micromeres) and four large blastomeres (macromeres) in the vegetal region.
- As cleavage progresses, the animal region becomes packed with numerous small cells, while the vegetal region contains only a relatively small number of large, yolk-laden macromeres.
- An amphibian embryo containing 16 to 64 cells is commonly called a morula.
- At the 128-cell stage, the blastocoel becomes apparent, and the embryo is considered a blastula.
- The blastocoel probably serves two major functions in frog embryos:
    a. it permits cell migration during gastrulation, and
    b. it prevents the cells beneath it from interacting prematurely with the cells above it.

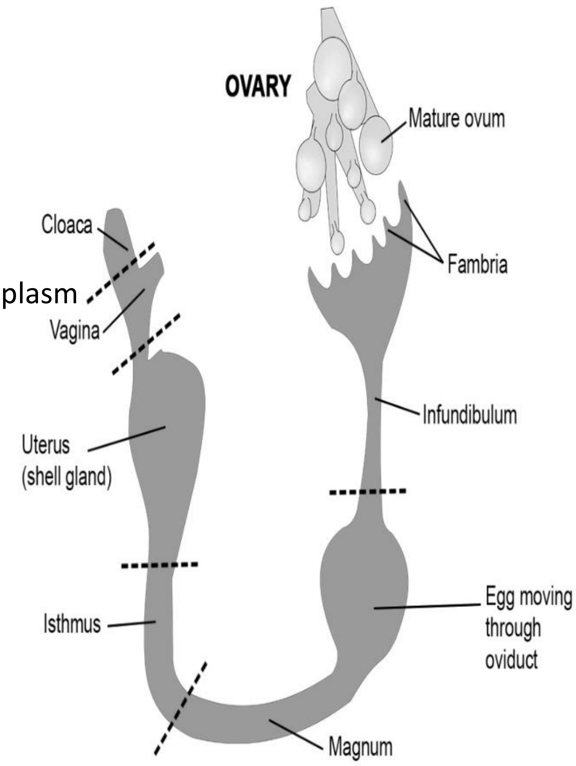
- Gastrulation is a phase early in the embryonic development of most animals, during which the blastula (a single-layered hollow sphere of cells) is reorganized into a multilayered structure known as the gastrula.

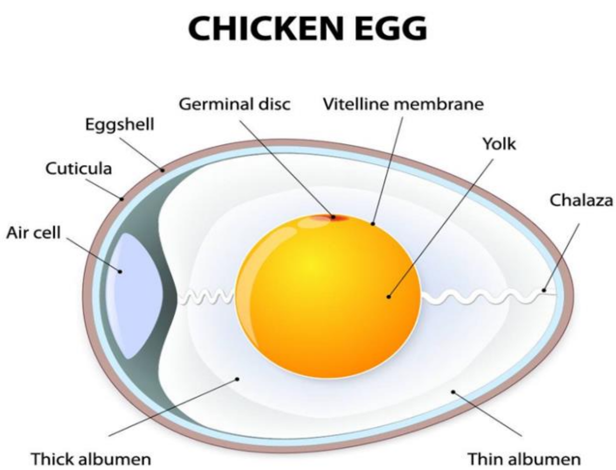


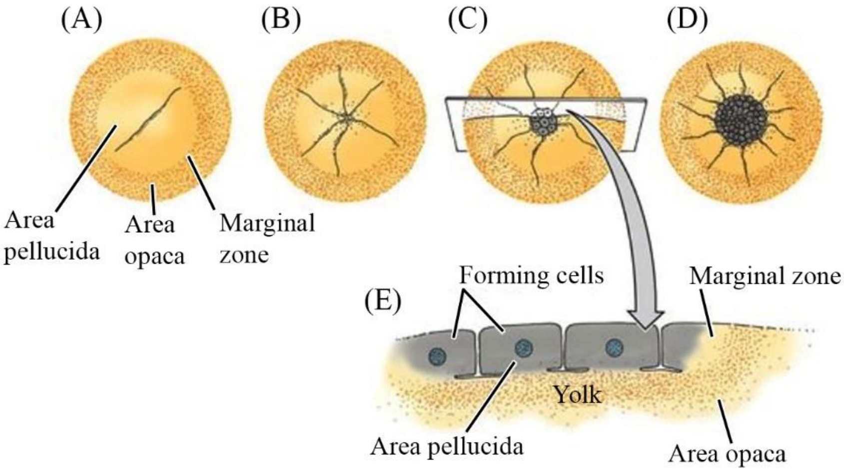
1. Gastrulation begins at the future dorsal side, below the equator when prospective endodermal cells (bottle cells) invaginate and form a slit (blastopore). The bottle cells line the early archenteron.
2. After the bottle cells, the next cells that enter the embryo form the prechordal plate, and the mesoderm of the notochord.
3. Simultaneously, the animal cells undergo epiboly, completely surrounding the surface of the embryo until a ventral lip of the blastopore forms.
4. The last endodermal cells on the surface appear as the yolk plug.
5. The yolk plug is eventually covered by ectoderm.

Avian Embryology

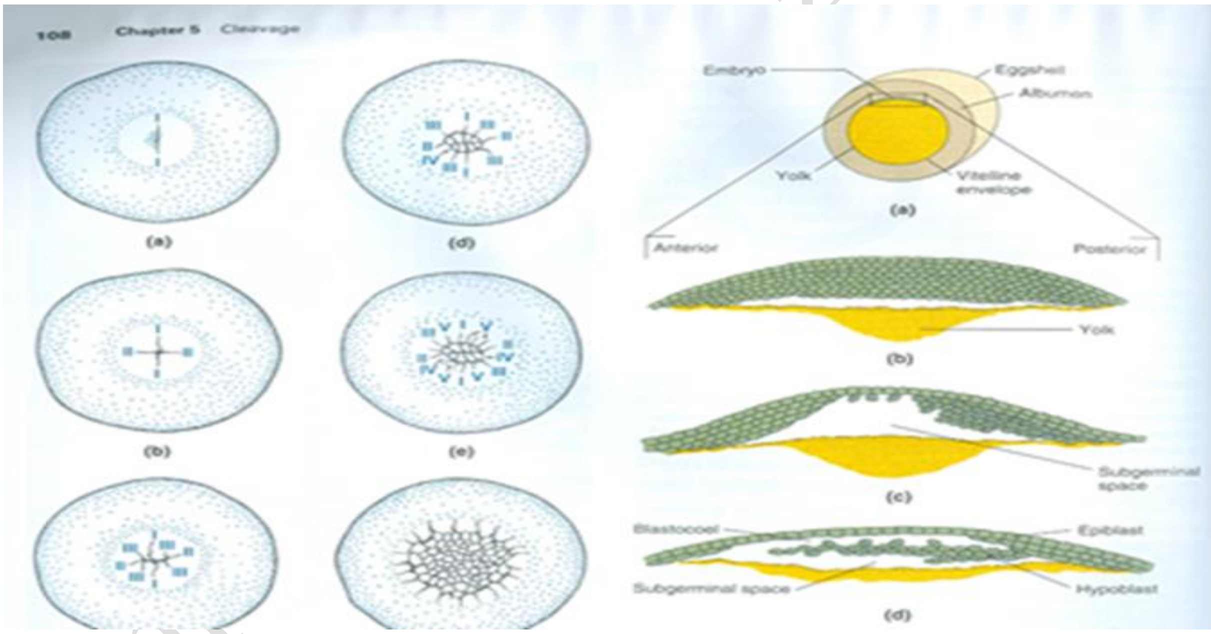
- Fertilization of the chick egg occurs in the oviduct, before the albumen and the shell are secreted upon it.
- The egg is telolecithal with a small disc of cytoplasm sitting atop a large yolk.
- Cleavage occurs only in the blastodisc, a small disc of cytoplasm 2-3 mm in diameter at the animal pole of the egg.



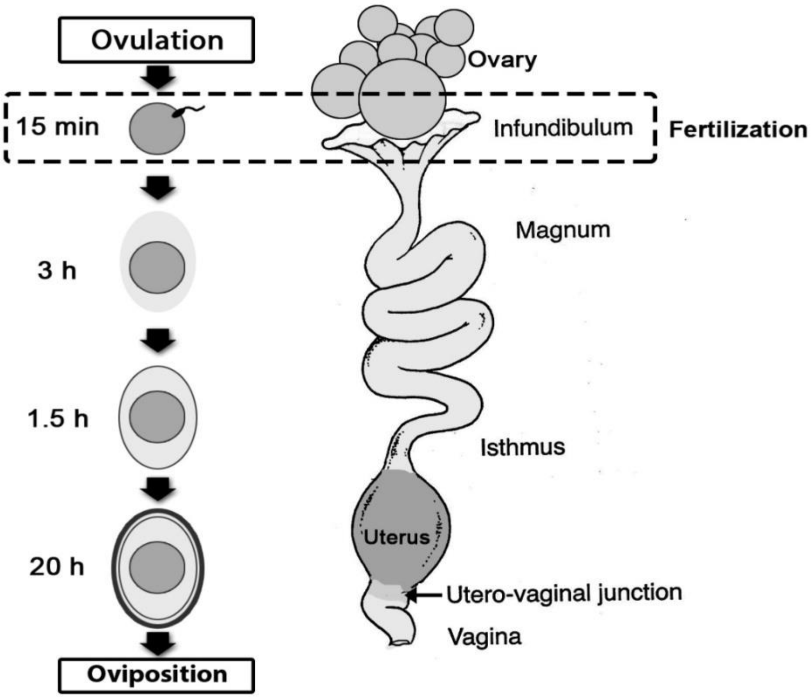




- The first cleavage furrow appears centrally in the blastodisc, and other cleavages follow to create a single-layered blastoderm.
- Thereafter, equatorial and vertical cleavages divide the blastoderm into a tissue five to six cell layers thick.
- Between the blastoderm and the yolk there develops a space called the sub germinal cavity.
- This space is created when the blastoderm cells disintegrate leaving a single layer of cells called area pellucida/Epiblast.
- The peripheral ring of blastoderm cells constitutes the area opaca.

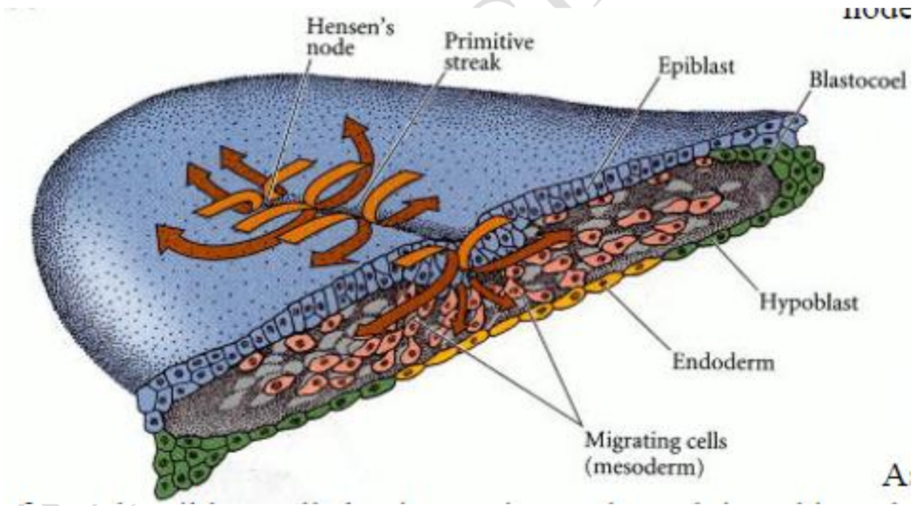


- From the epiblast the ingressing cells unite with the sheet of cells migrating from the posterior margin of the blastoderm to form the hypoblast.
- The hypoblast thus divides the subgerminal space into compartments: blastocoel and subgerminal space.
- The blastocoel between epiblast and hypoblast layers.
- This two-layered blastoderm (epiblast and hypoblast) gaped apart by blastocoel and joined together at the margin of the area opaca, is called blastula.
- The avian embryo comes entirely from the epiblast.
- The hypoblast does not contribute any cells to the developing embryo.
- The hypoblast cells form portions of the external embryonic membranes (Amnion, Chorion and Allantois, especially the yolk sac and stalk)



Primitive Streak

- The major structural characteristic of avian, gastrulation is the primitive streak.
- This streak is first visible as a thickening of the epiblast at the posterior region of the embryo.
- As these cells migrate from the lateral region of the posterior epiblast toward the center the primitive streak, that elongates toward the future head region.

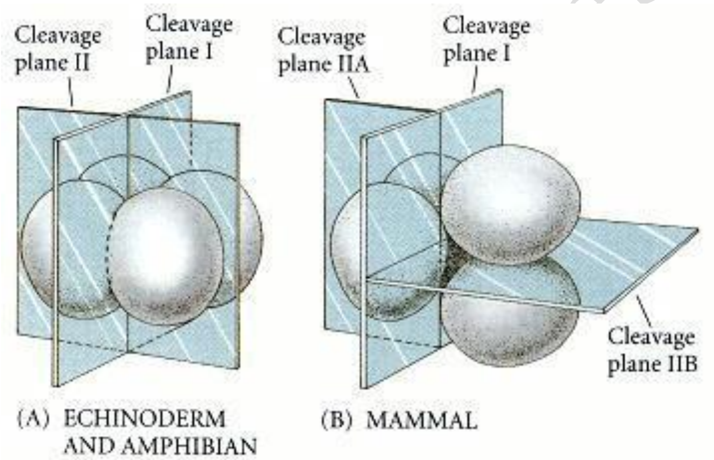


- The streak eventually extends 60 - 75% of the length of the area pellucida.
- The primitive streak defines the axes of the embryo. It extends from posterior to anterior end.
- As cells converge to form the primitive streak, a depression forms within the streak. This depression is called the primitive groove.
- This groove serves as an opening through which migrating cells pass into the blastocoel.
- At the anterior end of the primitive streak is a regional thickening of cells called Hensen's node.
- The center of this node contains a funnel-shaped depression, called the primitive pit.
- As soon as the primitive streak has formed, epiblast cells begin to migrate through it and into the blastocoel.
- The primitive streak has a continually changing cell population.

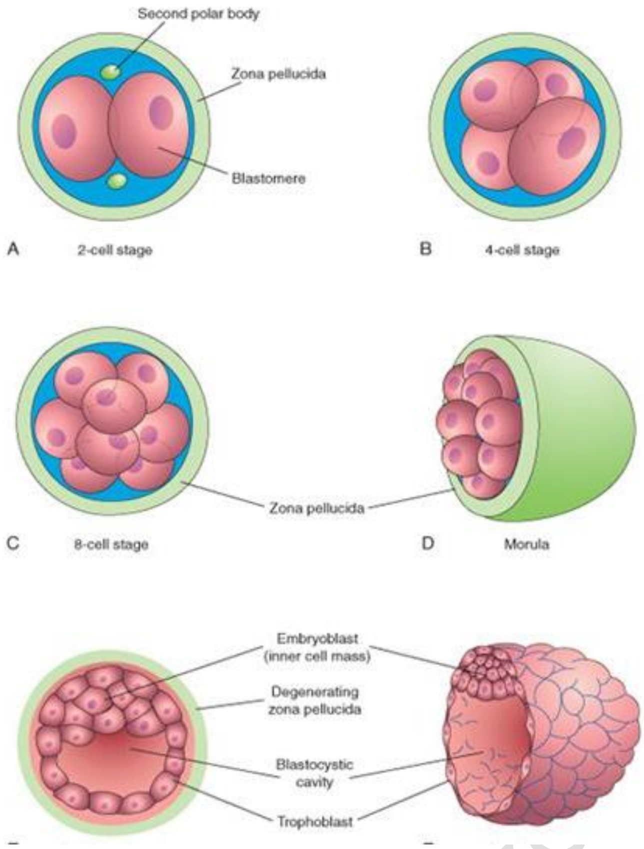
- Cells migrating through Hensen's node pass down into the blastocoel and migrate anteriorly, forming the notochord.
- The cells passing through the lateral portions of the primitive streak give rise to endoderm and mesoderm layers.
- The epiblast remain out side and is transformed into the ectoderm.
- Now this three layered embryo is called gastrula which has formed undergoing a process, the Gastrulation.

Gastrulation
- It is the process of highly integrated cell and tissue movements and their rearrangements so as to develop a three layered embryo composed of ectoderm, mesoderm and endoderm.

Mammalian Embryology
- The mammalian oocyte after its release from the ovary is swept by the fimbriae into the oviduct
- Fertilization occurs in the ampulla of the oviduct, a region close to the ovary.
- Meiosis is completed at this time, and first cleavage begins about a day later.



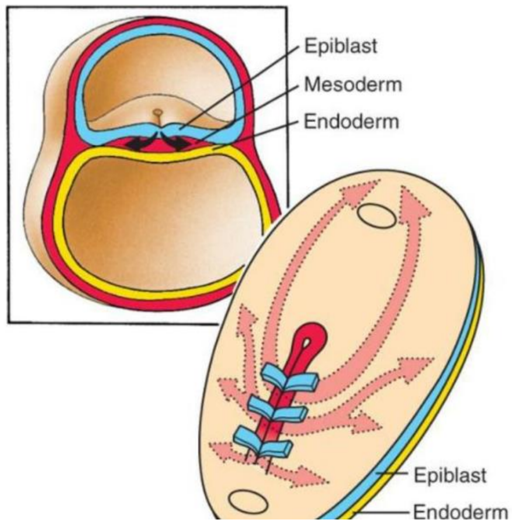
- The cilia in the oviduct push the embryo toward the uterus; the early cleavages occur along this journey.
- In mammals the cleavage is rotational cleavage.
- Following the third cleavage,, the 8 blastomeres undergo a spectacular change in their behavior.
- The 8-cell embryo divide to produce a 16-cell morula consisting of a small group of internal cells (Inner cell mass) surrounded by a larger group of external cells.
- Most of the descendants of the external cells become the trophoblast cells.
- This group of cells produces no embryonic structures.

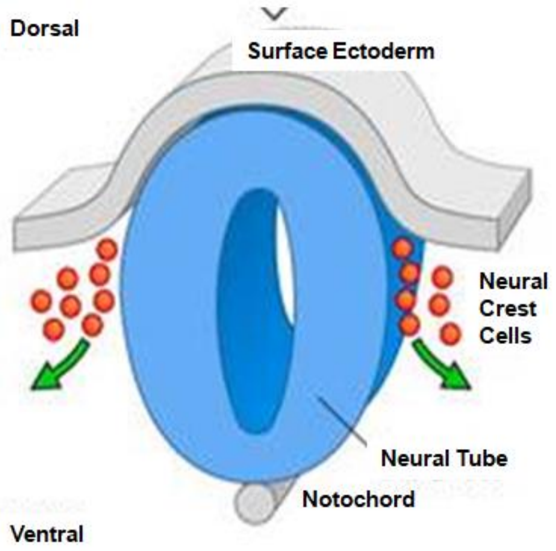


- It forms the tissue of the chorion, the embryonic portion of the placenta.
- The chorion enables the embryo to get oxygen and nourishment from the mother.
- In mammals the embryo proper is derived from the descendants of the ICM.
- The development of the embryo proper can wait until after that attachment occurs.
- The ICM is positioned on one side of the ring of trophoblast cells.
- The resulting structure, called the blastocyst.
- While the embryo is moving through the oviduct en route to the uterus, the blastocyst expands within the zona pellucida and ultimately hatches out.

Primary Germ Layers

- The germ layers develop early in embryonic life, through the process of gastrulation.
- During gastrulation, the embryo develops/differentiate into three primary germ layers:
    - an inner layer, endoderm,
    - an outer layer, ectoderm and
    - a middle layer, mesoderm.





Ectoderm

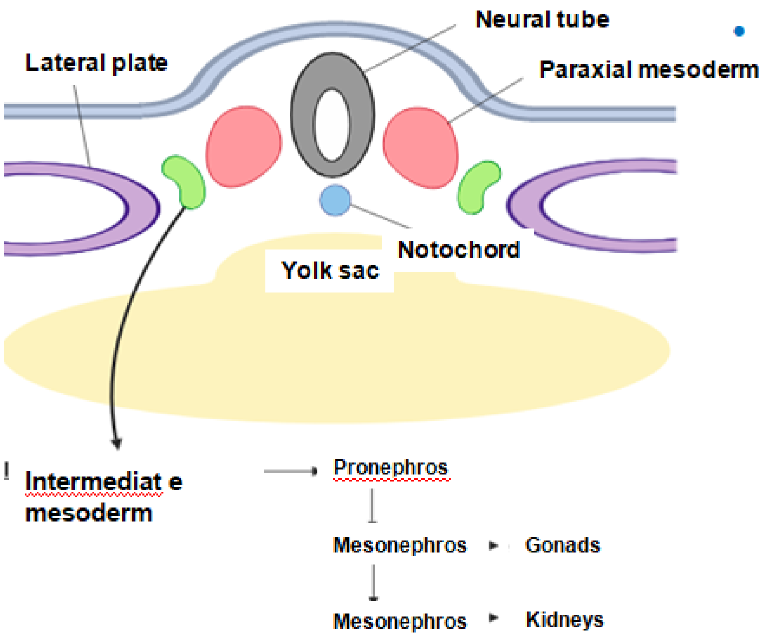
- The ectoderm develops from the embryo's epiblast.
- The ectoderm develops into the surface ectoderm, neural crest, and the neural tube.
- The surface ectoderm develops into: epidermis, hair, nails, lens of the eye, sebaceous glands, cornea, and tooth enamel, the epithelium of the mouth and nose and anterior pituitary.
- The neural crest of the ectoderm develops into: peripheral nervous system, adrenal medulla, melanocytes, facial cartilage (ear and nose)
- The neural tube of the ectoderm develops into: brain, spinal cord, posterior pituitary, motor neurons, and retina.

Endoderm

- The endoderm is one of the germ layers formed during animal embryonic development.
- Cells migrating inward along the archenteron form the inner layer of the gastrula, which develops into the endoderm.
- The endoderm gives rise to:
    - the epithelial lining of the gastrointestinal and respiratory tracts;
    - the liver, the thymus, the thyroid, the parathyroids, and the pancreas;
    - the epithelial lining of the urinary bladder and urethra;and
    - The epithelial lining of the tympanic cavity, tympanic antrum, and auditory tube.

Mesoderm

- The mesoderm forms in the embryos of triploblastic animals.
- During gastrulation, some of the cells migrating inward contribute to the mesoderm, an additional layer between the endoderm and the ectoderm.
- The formation of a mesoderm leads to the development of a coelom.



- The mesoderm has several components which develop into tissues:
  - intermediate mesoderm,
  - paraxial mesoderm,
  - lateral plate mesoderm and
  - Chorda-mesoderm.
  - Human body.

- The chorda-mesoderm develops into the notochord.
- The intermediate mesoderm develops into kidneys and gonads.
- The paraxial mesoderm develops into cartilage, skeletal muscle, and dermis.
- The lateral plate mesoderm develops into the circulatory system (including the heart and spleen) and the wall of the gut.